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OPTICAL DEFECTS OF THE EYE.

THE OPTICAL

DEFECTS OF THE EYE,

AND THEIR CONSEQUENCES,

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ASTHENOPIA AND STRABISMUS.

BY

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PREFACE.

AFTER having read Professor Donders's papers on the "Anomalies of Refraction and Accommodation of the Eye," in the *Archiv fur Ophthalmologie,* I in 1860 visited Utrecht, for the purpose of more completely studying the views of the eminent Professor, from whose writings I had already derived so much advantage. I take this opportunity of publicly thanking Professor Donders and Drs. Snellen and Haffmanns for the uniform kindness and courtesy which I experienced from them during my stay at Utrecht. After my return from that town, I commenced to submit what I had learnt there to the test of practical experience at the Ophthalmic Hospital, Southwark. The results of that experience, collated from the written records of a large number of cases, I now give to the Profession in this humble tribute to the general importance and accuracy of those researches which have shed so brilliant a halo around their author.* The frequent references to the works of Mackenzie, v. Gräfe, and Giraud-Teulon, are in themselves, I trust, a sufficient acknowledgment of how indebted I am to the writings of those distinguished ophthalmologists. Nor should I omit to specially mention the admirable work of Porterfield, which, after the lapse of upwards of a century, still holds its ground as a standard authority on the Optics of the Eye.

---

* A part of this essay has already appeared in the *Medical Times and Gazette,* in a series of Lectures, the literary form of which I have not thought it necessary to alter.

Finally, I would venture to hope that the following pages may be found a useful Introduction to the comprehensive Treatise of Professor Donders, in the twenty-second volume of the New Sydenham Society's works.

J. Z. L.

30, *Devonshire Street, Portland Place,*
April, 1865.

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OPTICAL DEFECTS OF THE EYE.

CHAPTER I.

OPTICAL CONSIDERATIONS.

IN the present course of lectures I propose giving an account of those defects of vision which depend either upon a misformation or a perversion of function of the optical structures of the eye. Up to a comparatively recent period the pathological deviations of the refractive and accommodative powers of the eye were, from the want of any system in their discrimination, involved in such hopeless confusion, that the determination of the glasses requisite for their correction became unsatisfactory and empirical in the last degree: the error was, most ophthalmic surgeons rested satisfied with but a superficial knowledge of optics, whilst opticians regarded the eye rather as a production of their workshops requiring some correction, than as a structure of the human body, endowed with all the attributes of vitality. I shall, therefore, not conceive the time ill-spent, if we confine our attention, in the first instance, to optics considered as a pure science,* altogether independent of the applications we shall hereafter have to make of our knowledge thus acquired. To attempt to understand the optical construction and defects of the eye without such a previous knowledge, is simply irrational; and it is to the absence of any such preliminary information that I am led to ascribe the unintelligible character which most of the communications hitherto published on this subject have possessed for the profession at large.

---

* In the course as actually delivered by me at the Ophthalmic Hospital, Southwark, *all* the leading phenomena of optical science, as the laws of reflection and refraction, &c., were fully discussed; but as these subjects are but imperfectly intelligible without such experimental illustrations as I then produced, I have omitted them in the lectures as now published, proceeding at once to the consideration of optical lenses, a knowledge of which is essential for the due comprehension of the physiological and pathological optics of the eye.

The eye is, in its most important relations, essentially an optical instrument, through whose medium we take cognisance of the most obvious and necessary events of the external world. This, in its turn, becomes the subject of our visual observation by that physical force which we understand by the term "light."

Light is one of those agents of nature the existence of which is inferred from its effects, just as that of heat, electricity, mechanical or vital force is inferred from their effects. The effect of light which principally concerns us is that which it exercises on the retina; but photography, magnetism, vegetation, all demonstrate the existence of light as a perfectly independent physical agent. In other words, supposing all the world were blind, still light would exist, even in its purely optical sense: it would still be reflected, refracted, polarised, although we should be unable to recognise any such effects. Some of the bodies of nature are, in themselves, sources of light—*self-luminous*—such as the sun, the stars, bodies in a state of ignition. On the other hand, most bodies are not self-luminous, but derive their luminosity from reflected light, which itself is, in the first instance, derived from self-luminous bodies. Thus, the objects in a perfectly dark chamber only become visible by the introduction of a light; extinguish this latter, and they are no longer seen.

For the sake of precision in the investigation of the laws of the propagation of light through space, it is necessary to consider all luminous bodies as composed of an infinite number of infinitely small luminous points, each of these points to give off, in all possible directions—radiate—an infinite number of straight lines of light of extreme tenuity. These lines of light are individually called *rays* of light, whilst the combined bundle of rays which emanate from, or converge to, a luminous point is called a *pencil* of rays.* If the component rays of a pencil of light, in their onward progress from their initial source — the luminous point — separate further and further from each other, then we have before us a *divergent* pencil (Fig. 1); if, on the other hand, the rays approach each other closer and closer as they proceed onwards to a point, then we have a *convergent* pencil (Fig. 2); whilst, lastly, if the rays of a pencil neither diverge nor converge in their onward course, we have a *parallel* pencil (Fig. 3). A luminous point is termed, in the language of optics, a *focus* of rays, or, shortly, a *focus*.

FIG. 1.

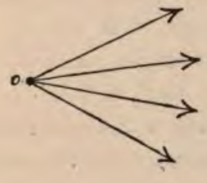


FIG. 2.

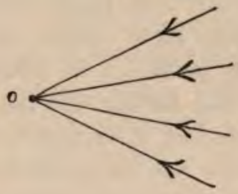


FIG. 3.

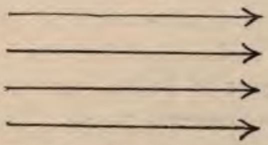


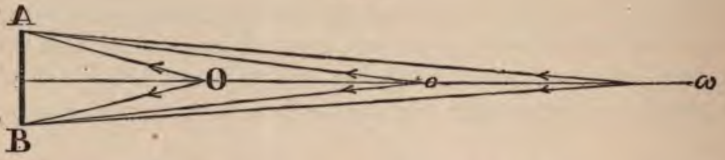
FIG. 1.—Divergent Pencil } *o*, luminous point, or *focus*.
,, 2.—Convergent ,,
,, 3.—Parallel ,,

As an illustration of divergent and convergent pencils, the case of the flame of a candle before which a convex lens is held may be taken. The rays of light diverge *from* the constituent luminous points of the flame, and are converged *to* as many points again by the lens, as we shall discuss fully at a later period of these lectures. From what has been before said, it may be inferred that all luminous bodies emit their rays of light in the form of divergent pencils. If a luminous point (*O*, Fig. 4), be at a certain distance from a recipient

---

* We may obtain an approximate concrete idea of a "ray" of light by allowing the light from the sun to pass into a dark chamber through the minutest possible hole drilled in a thin plate of metal; enlarge this hole, and several rays, constituting a "pencil" of light, will enter the chamber.

FIG. 4.



surface, *AB* (the pupil of the eye, *e.g.*), any two divergent rays form some angle, as *AOB*, with each other; if the luminous point (*o*) be further off, the angle, as *AoB*, will be less; if still further off, the angle, as *AωB*, still less; and so on. This fact is obvious to the eye from a mere inspection of Fig. 4; but it is also geometrically demonstrable (Euclid i., 21). Following up the same reasoning, if we suppose the luminous point infinitely far off, any two proximate rays will form no angle at all with one another—will be, in a word, *parallel*, it being in all cases understood that the surface on which the rays of light impinge is of limited extent in comparison with its distance from the luminous point. Thus, if a candle flame is, say, twenty feet from us, the rays of light from each luminous point which strike the area of the pupil of the eye form practically parallel pencils, and *à fortiore*, in ascending progression, those which strike the pupil from a lighthouse, from the sun, from the fixed stars. But if the recipient surface on which the rays of light from a candle flame fall be, say, a large target, from the lighthouse a large extent of the ocean, from the sun the earth, from the fixed stars the entirety of space, we may, in the first two instances certainly, in the two latter not unreasonably, assume that the pencils of rays are of a divergent character in regard to the magnitude of the surfaces on which they fall. Strictly speaking, then, no such rays as parallel rays exist in nature; but for the recipient surfaces we shall have to deal with, our eyes, lenses, reflectors, &c., we may practically regard all rays of light which proceed from near objects as divergent, those from distant ones as parallel, whilst convergent rays are not to be found in nature at all, but may be produced by certain optical means, of which we shall soon come to speak.

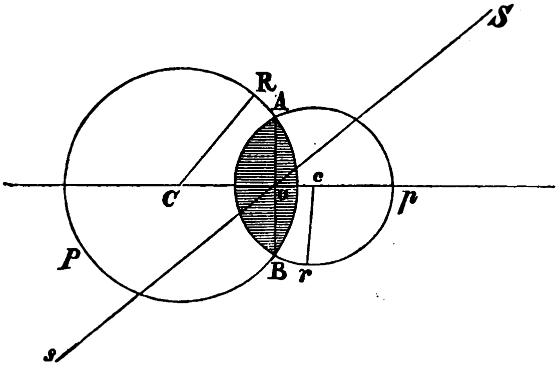
What evidence have we of all the above assumptions? Their truth is inferred from the fact that most optical phenomena are only deducible from such assumptions, and that the laws of optics hence deduced have not only led, by a chain of inferences, to the explanation of more complex phenomena, but have served as the landmarks to the investigation of, up to the time, unknown fields of discovery in optical science. Two different theories have been advanced of the more intimate nature of light. The Newtonian (corpuscular) conceives each luminous point to be constantly giving off a succession of luminous corpuscles, which follow each other in uninterrupted succession on an imaginary axis, like a string of beads coursing along a rigid thread. The undulatory theory, on the other hand, considers space as pervaded by a subtle gaseous fluid or ether; that luminous bodies have the power of communicating to this ether a wave-motion, which affects the retina, just as the undulations of the atmosphere from vibrating bodies affect the auditory nerve, or, to take a ruder simile, as the waves of the ocean impart their movements to the vessel that rides on them. The undulatory theory is of far wider significance, however, than its mere physiological application. Sir John Herschel, speaking of it, says, "It is a theory which, if not founded in nature, is certainly one of the happiest fictions that the genius of man has yet invented to group together natural phenomena, as well as the most fortunate in the support it has received from all classes of new phenomena, which at their discovery seemed in irreconcileable opposition to it. It is, in fact, in all its applications and details, one succession of *felicities*, inasmuch that we may almost be induced to say, 'If it be not true, it deserves to be.'"

We shall now proceed to the, for our purpose, most essential part of the subject—viz., to the consideration of the properties of optical lenses.

The double-convex lens is represented in section in Fig. 5. It is formed by the apposition of segments of two spheres.

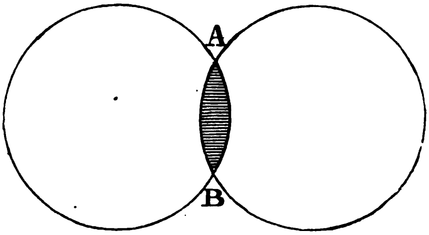
With the centre *C* and radius *C R*, describe the circle *C R P*, and with the centre *c* and radius *c r*, describe the circle *c r p*; the part *A B*, common to both circles, represents the vertical section of a double-convex lens. *C c* are the centres of curvature; *C R*, *c r* radii of curvature of the lens. A line *C c*, drawn through the two centres, is called the principal axis; the line *A B*, perpendicular to the axis, the diameter; the centre of this line *O* the optic-centre of the lens; whilst lines passing through *O*, as *S o s*, are secondary axes of the lens.

FIG. 5.



C, *c*=centres of curvature
C R,*c r*,=radii of curvature
C c=principal axis
A B=diameter
O=optic centre
S o s=a secondary axis
of the lens *A B*.

FIG. 6.



In the convex lenses in general use for spectacles, the radii of curvature of the two surfaces are equal. We then have a double equi-convex lens (*AB*, Fig. 6).

Parallel rays (*i. e.*, as I have before mentioned, such as emanate from luminous objects at a distance from the lens; practically, I find experimentally that for a lens of about an inch and a-half diameter, this distance is anything beyond four feet) entering one surface of the lens, are found, on their exit from the second surface, to have converged to a point at a fixed determinate distance from the lens.

This point *F* (Fig. 7) is the *focus* of parallel rays—the *principal focus* of the lens, or, briefly, the *focus* of the lens. The distance of this point from the contiguous surface (strictly speaking, from the optic centre) of the lens, *F A*, is the *principal focal length* of the lens, or briefly, the *focal length* of the lens. This, in the case of an equi-convex glass lens, equals the radius of curvature. Thus we speak of convex lenses of 2, 3, 5, 8, &c., inches focal length, or, as they are commonly termed, 2-inch, 3-inch, 5-inch, 8-inch, &c., convex lenses—meaning thereby that such lenses have the property of converging parallel rays to a focus, uniting them to a point, at distances from the lenses of 2, 3, 5, 8 inches respectively.* To make a practical application of our knowledge:—A person comes to you with a pair of convex glasses, but he has forgotten their focal length, and you wish to find this out; all you have to do is to see at what distance the image of any distant object (such as of objects in the street, of the sun, &c.) is formed most distinctly on a sheet of paper. Measure the

FIG. 7.

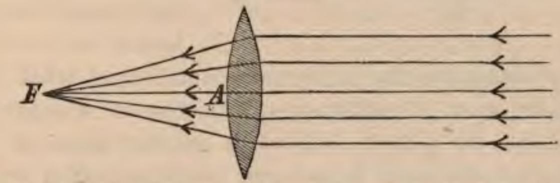


FIG. 7.—*F A.*=principal focal length, in an equi-convex glass lens equals the radius of curvature.

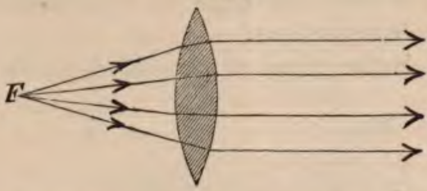
---

* I strongly recommend all persons who wish thoroughly to understand the subject of these lectures, to actually perform themselves all the experiments which are adduced. A set of trial lenses, and a few stands to hold them, &c., constitute all the apparatus required.

distance of the lens from the image, and you at once have the required information.

Vice versâ, rays of light which diverge from a point F (Fig. 8), situate at the focal length of the lens, issue from the other side in a state of parallelism. Many light-house lanterns are constructed on this principle, the light being placed at the focus of a convex lens.*

FIG. 8.



It is necessary to the right understanding of what follows, to here mention a well-known property of convex lenses. If an object be placed behind a convex lens at a less distance than its focal length, an erect magnified image of the object is perceived by an eye placed in front of the lens. Now, the shorter the focal length of the lens, the greater its magnifying power—*e.g.*, a 2-inch lens magnifies more than a 4-inch lens. In reference to their respective magnifying powers, then, we should be wrong in designating the first lens as 2, the second as 4, which would imply the second were "stronger" than the first; but the more correct expression is to call the first lens a $\frac{1}{2}$, the second a $\frac{1}{4}$, the latter fraction being less than the former. This nomenclature is strictly true, if we understand by the word "power" of a lens its deflecting power on the rays of light that strike it; so that, *e.g.*, a lens of $\frac{1}{12}$ is one that unites parallel rays to a focus at a distance of twelve inches from its surface, a lens of $\frac{1}{24}$ one that unites them at twenty-four inches, and so forth. [Vide note to p. 15.]

Designating, then, in this way convex lenses by fractions, of which the numerators are 1, and the denominators the focal lengths of the lenses, let me announce to you a most important proposition: the optical effect of a combination of lenses in contact, both as regards its power and as regards the distance at which parallel rays impinging on the first lens are brought to a focus by the combination of lenses, is always given by adding the several fractions, which express their respective powers, together. The resultant fraction represents the power of the single lens, which is optically equivalent to the whole set. Thus, suppose we wish to know the focal length of the combination of an 8-inch and of a 5-inch convex lens, placed together, we have, $\frac{1}{8} + \frac{1}{5} = \frac{1}{3}$ nearly. The equivalent single lens is a 3-inch lens. Parallel rays impinging on such a combination will be focussed at a distance of three inches.*

---

* I may here call attention to the fact, that, in the French trial-lenses, the focal lengths are given in Paris inches, whereas English opticians give theirs in English inches. 12 English inches = about 11¼ Paris inches; so that, *e.g.*, if we find a patient requires a 22½-inch glass of the French trial-glasses, we should order him a 24-inch English glass. In the German trial-lenses (Paetz & Flohr's) the Prussian inch is adopted, which differs but slightly from the English inch.

We have now considered the optical effect of a convex lens on parallel rays, such as emanate from objects at any distance greater than four feet from the lens. But suppose the object situate at any less distance, but greater than the principal focal length, from the lens, then the rays of light which proceed from each luminous point are no longer parallel, but divergent. It will now be found the lens still retains its power of re-uniting the rays to a point—of focussing them. But the focus is now further off the lens than the principal focus. I think I may explain this result by a very simple demonstration. Take the case, *e. g.*, of a 6-inch convex lens. Such a lens unites parallel rays to a focus at six inches. Suppose, however, the rays of light, instead of being parallel to, diverge from, a luminous point, say, twenty inches distant from the lens, then, as I have before said, they would, after passing through a 20-inch lens, issue parallel. Now, a 6-inch lens may (according to the proposition before announced) be considered as equivalent to the combination of a 20-inch lens and a 9-inch lens; for $\frac{1}{6}=\frac{1}{20}+\frac{1}{9}$ (nearly). So that we may assume that that part of the 6-inch lens which is equivalent to a 20-inch lens has been employed in converting the rays diverging twenty inches from its surface into parallel ones; these then strike that remaining part of the 6-inch lens which is equivalent to the 9-inch lens, and are, therefore, brought to a focus at nine inches from this latter. So that the final result is, that rays diverging from a luminous point twenty inches from a 6-inch convex lens are brought to a focus at a distance of nine inches from its surface.*

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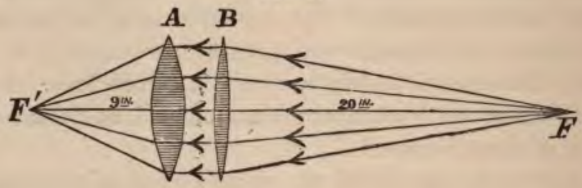
* If any of the lenses are concave ones, their powers must be subtracted. If the resultant fraction is negative, this indicates that the entire combination is equivalent to a concave lens.

Fig. 9 illustrates the presumed theory graphically:—

FIG. 9.



B=20-inch lens } Together equivalent to a 6-inch lens.
A=9-inch lens }
F=a luminous point, twenty inches from B.
F'=focus of combined lenses, nine inches from A.

As the luminous point approaches nearer and nearer to the lens, the focus of the emergent rays moves further and further off, till, as I have before said, when the luminous point arrives at the principal focus of the lens, the emergent rays are not united to a focus at all, but issue parallel to one another.

We are now prepared to understand how a convex lens possesses the power of forming an *image* of an object placed in front of it. As I have before explained, every object in nature may be considered as composed of an infinite number of points, either in themselves luminous or rendered so by reflected light, every such luminous point emitting a pencil of rays, either divergent or parallel, according to the distance of the object from the surface on which the rays fall. If the rays of any one pencil are made to again converge, the luminous point from which they in the first instance emanated is, so to say, again reproduced at their point of union (focus). In this way, each luminous point of the object having its optical representative, an "image" of the object is formed. We understand, then, by the term "image" of an object, its optical reproduction. An object has certain physical properties: its extension in space, its power of affecting our sense of touch. It may possess heating or electrical attributes, and, as a rule, always has an optical existence. Certain bodies, however, such as some gases, having neither any inherent nor acquired luminosity, may be said to have no optical existence; at any rate, as far as our means of ascertaining any such existence extend, although they may have certain optical properties, such as the power of refracting or polarising the light emitted from other bodies. If you regard yourself in a looking-glass, you see yourself optically reproduced, but not in any other sense; your image conveys to you no direct information of any other physical properties you may possess; you cannot, hence, directly infer whether your flesh is hard or soft, whether your body feels hot or cold, whether you are in any particular electrical state, &c. Your image in the glass is your optical reproduction, and nothing more.

---

* We may hence deduce the practical rule: To find the focus of rays diverging from any given distance from a convex lens of known focal length, subtract from the power of the lens the fraction whose numerator is unity, and whose denominator is the distance of the object from the lens; the resulting fraction reduced to a fraction whose numerator is unity gives in its denominator the distance from the lens to which the rays will be converged to a focus by the lens. My friend Dr. Giraud-Teulon, of Paris, has based an ingenious view of the action of lenses generally on the theory in the text. This theory he, I know not how far correctly, has ascribed the origination of to myself (Vide *Annales d'Oculistique*, Tome LII., p. 261).

If in a plate of metal a minute aperture is drilled, and on one side of the plate an object (the flame of a candle) be placed, whilst on the other side is a sheet of paper, an *inverted* image of the flame will be observed on the paper. To understand this result, we must premise that light travels only in straight lines. Look at the sky through a flexible tube; bend the tube, and the sky will no longer be perceived.

Let $A B$ (Fig. 10) be an object from every point of which a pencil of divergent (or parallel, as the case may be) rays proceeds (only those which proceed from the top and bottom of the object are represented in the figure), $P P'$ a plate of metal perforated at its centre C, so as to admit of but a single ray of light passing through it, *S S′* a sheet of paper. A single ray, as *A A* and *B B*, from each point of the object will strike the paper, and hence, being reflected to the eye, *E*, of an observer, a distinct *inverted* image, *B A*, of the object will be perceived. It will be remarked, that the inversion of the image is caused by the fact that rays of light only travel in straight lines.* A simple inspection of the figure shows that if the sheet of paper is as far behind the aperture in the plate as the object is in front of it, the image (*B A*) will be equal in size to the object; if closer, less ($\beta\ \alpha$); if further off, greater ($b\ a$). As of all the rays that diverge from each luminous point of the object only one of each pencil strikes the paper (the rest being cut off by the opaque plate of metal), it follows that the

FIG. 10.

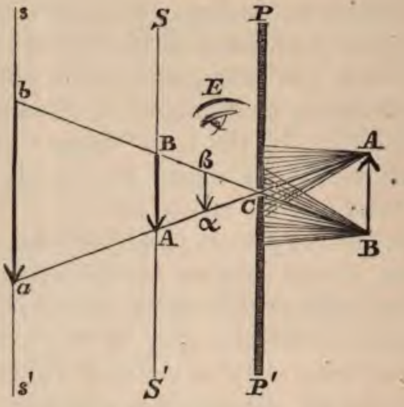
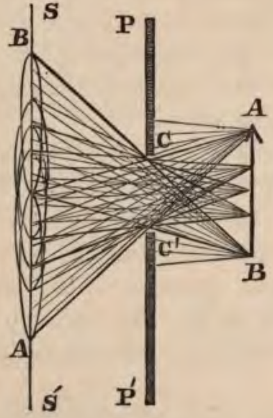


FIG. 11.



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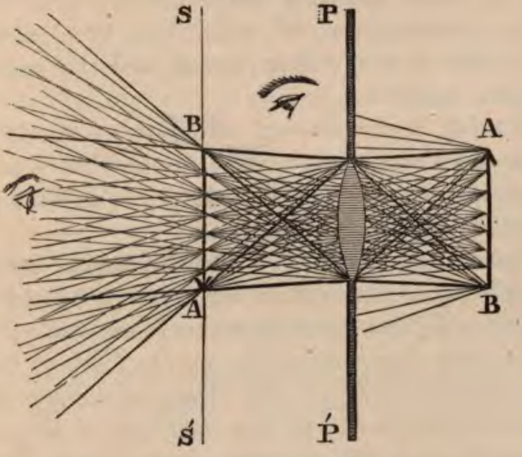
* In such an elementary exposition as the above, I ignore the inflexion of light.

image will be greatly inferior in brightness to the object. If we, as in Fig. 11, increase the aperture in the plate, more rays of the pencils from each point of the object are received on the paper, but each point of the object is no longer represented by a point, but by a *circle* (the section of each conical pencil of rays) on the paper: these circles ("circles of diffusion") from contiguous points necessarily overlap; hence the image is no longer a faithful optical representation of the object, but appears blurred and indistinct.* In other words, we have lost in definition what we have gained in brightness by the enlargement of the aperture in the plate. Suppose we now, in the enlarged aperture $C\ C'$, place a double convex lens, then the rays of each divergent pencil, from every luminous point of the object, will be reunited by the power of the lens into a corresponding luminous point in the image, and we shall obtain (Fig. 12) all the advantages of distinctness of

Fig. 12.



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* In the case of imperfect accommodation of the eye, the "circles of diffusion" on the retina take the form of the pupil. I have found a piece of coarse calico affords a ready method of studying these circles. The interstices between the threads appear on imperfect accommodation as multitudes of overlapping circles, which vary in size, illumination, &c., with the size of the pupil, with the addition of convex or concave lenses, &c.

definition combined with a due degree of luminosity in the image. An eye in front of the paper will perceive an inverted image of the object by reflected light; if an aperture be made in the paper, an eye placed behind the aperture will see an inverted image of the object, suspended, as it were, in the air (an "aërial image"), formed by the rays of the convergent pencils which produce the image, diverging again after their reunion. If the object be at a considerable distance from the convex lens, of course the image will be formed at its principal focal length; after the object is about four feet from the lens, as it approaches nearer, so the image recedes, and at the same time becomes larger; when it is at the principal focus, no image at all is formed; a circle of diffused light, in the case of a flame, the size of the lens, is alone visible. A little reflection shows these facts to be an immediate consequence of what has been already said regarding the foci of convex lenses, and the optical effects of a minute aperture.

I now wish to direct your attention to some phenomena which are the direct consequences of what has preceded, and which are of great importance in the physiology and pathology of the optical apparatus of the eye.

If we place a candle-flame at a considerable distance from an 8-inch lens, a screen placed eight inches behind this latter will exhibit a distinct inverted image of the flame; if we now bring the flame closer to the lens, say, to fourteen inches from it, this approximation of the object is accompanied by a corresponding recession of the image;* *if the screen still remains at* 8″, only an indistinct, blurred, *quasi* image of the flame will be seen; but by placing a 14-inch lens next to the 8-inch one, we re-obtain a perfectly distinct (larger) image of the flame on the screen. The *rationale* of this is very simple; the 14-inch lens has the effect of rendering parallel the rays which diverge from each luminous point of the object fourteen inches in front of it; these parallel rays impinging on the 8-inch lens are then focussed at eight inches—the original position of the screen. Of course, for the two (14- and 8-inch) lenses we may substitute a single 5-inch one; for $\frac{1}{14}+\frac{1}{8}=\frac{1}{5}$ (nearly). As we shall see further on, this is precisely what occurs in the human eye, in the act of accommodation for near objects.

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* In fact, the distance behind the lens at which a distinct image of the flame is formed is 19″, so that the screen must be moved eleven inches further back for the observation of a distinct image.

The converse experiment is important in the theory of myopia. The flame being at a considerable distance off, and the screen being at eight inches from the 8-inch lens, substitute for this latter a 5-inch one: no distinct image of the flame then appears on the screen. Now place a 14-inch concave lens next to the 8-inch convex one, and a distinct image on the screen is at once produced. After what has preceded, the equation, $\frac{1}{5}-\frac{1}{14}=\frac{1}{8}$ (nearly), sufficiently explains the above result.

In all the cases we have been hitherto considering, the rays of light which converge to form the image actually meet, and may be received on a screen; or, if we remove this latter, the aërial image may, by a little attention, be seen suspended in the air, as it were—to be an "aërial image," as it is termed. But as soon as the object approaches the lens to a distance anything less than the principal focal length of this latter, a remarkable change ensues; the image all at once transplants itself to the same side as the object, and simultaneously becomes erect and magnified.* (Before, it was on the contrary side of the lens to the object, and inverted.) This image, however, cannot be received on a screen. It is not, as in the case of the inverted image, a *real*, but only an *imaginary* (virtual) one; or, if I were to designate the real image as a *physical*, I should call the imaginary a *physiological* one.

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* A convex lens used as a magnifier, in the sense referred to in the text, is simply an artificial addition to our accommodation, which enables us to view the object under a greater angle than we otherwise could do. This, in combination with a mental reference of the image to a further plane of projection than the object itself really occupies, explains the "magnifying power" of the lens. The word "power" has been used rather loosely in optical science. In the text we have used it in the sense of *magnifying* power (M). This M appears to depend on (1) the focal length of the lens, (2) the state of refraction and accommodation and acuteness of vision of the eye, (3) on a formula given by Parkinson at p. 179 of his Treatise on Optics. At p. 89 of this same work, the word "power" of a lens is arbitrarily defined as the reciprocal of its focal length. Giraud-Teulon has very lucidly explained (in the *Annales d'Oculistique* for July, 1864) that the word "power" must, in the latter case, be taken to represent the con- or di-verging power of a lens on rays of light. In this sense the power of a lens is strictly inversely proportional to its focal length.

If this course were one of pure optics, I should now bring before you the subject of concave lenses; but as these find their application in myopia, I shall defer speaking of them till I come to that part of our subject.

CHAPTER II.

PHYSIOLOGICAL OPTICS.

THE human eyeball is, from before backwards, about $\frac{19}{20}$ of an English inch.* In it exists a system of convex lenses composed of the aqueous chambers, the crystalline lens, and the vitreous humour. These lenses differ, *inter alia*, from the glass ones we have hitherto been speaking of, in being soft, and thus capable of being modified in their degrees of curvature—in their focal lengths †—by certain muscles. When we regard a distant object, these muscles are in a state of relaxation, or, at any rate, of tonic contraction. The eye is then said to be in a "state of rest;" its lenses preserve one fixed curvature. The three lenses of the eye we may, for all practical purposes, consider as equivalent to a single 1-inch glass convex lens (more accurately to one of $\frac{18}{20}$ inch). The crystalline, Monro states to have a focal length of $\frac{3}{8}$ inch. When the eye is in a state of rest, the image of a distant object is formed exactly on the *retina*, and may there be seen.‡ The retina thus closely resembles the screen of our previous optical experiments, or the ground glass of an ordinary camera obscura;§ the curved surface of the retina is however much better adapted to receive an accurate image than the flat surface of the ground glass of the camera is.

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* Professor Ed. Jäger found the average length of the axis of eighty adult eyes to be 24·3 millimetres; that of seventy eyes of new-born infants to be 17·53 millimetres.

† Both in convex and concave lenses it may be asserted, generally, that the shorter the radius of curvature (or the greater the degree of curvature), the shorter the focal length of the lens (or the greater its power).

‡ If we carefully cut away the sclerotic in the sheep's eye, a distinct inverted image of any distant object may be seen to be formed on the retina. The eye of an albino rabbit shows the same thing without any further preparation.

§ John Baptista Porta, the inventor of the camera obscura, in his "Magia Naturalis" (1560), thought that the pupil played the part of the minute aperture in his camera, and that the crystalline lens was the recipient surface of the image. It was reserved for Kepler, forty years later, to prove the true functions of the lenses of the eye.

How it is that the purely physical image thus formed, translated to the mind (*sensorium*), through the medium of the optic nerve, produces to us an accurate idea of the object itself, as regards position, size, form, colour, &c., is more than we at present know, any more than how the different vibrations impressed on the auditory apparatus convey to the mind the various ideas of musical and other sounds.* But, at the same time, it is most important to bear in mind the mental (psychical, nervous) nature of vision—its partly subjective, as contrasted with its partly objective character; † otherwise, we might often be misled into ascribing defects of vision either to optical or organic causes, which depended rather on some perversion of the sentient apparatus. Nevertheless, it is remarkable how perfectly the purely optical functions of the eye must be exercised before vision can be accurate. For the distinct perception of objects their images must fall exactly *on* the retina. If a normal eye be in a state of rest, the images of all *distant* objects fulfil this condition, and vision is perfect. Suppose, now, the eye, with its lenses still remaining in this state of equilibrium, be directed to a *near* object, the image would be formed behind the retina. I say "would be," because, in reality, the retina having no power of locomotion backwards, only an indistinct quasi-image is formed on it by the circles of diffusion, as I have before fully explained in the case of a convex lens. The retina remaining stationary, an increase of curvature—power—of the crystalline would, as you can, from what I have before said (p. 14), now readily understand, bring the image back on to the retina; and this is, in fact, precisely what occurs in the human eye. The images of near objects are brought back on to the retina by the crystalline lens becoming more convex. This was first partially proved by Young, much more completely so by Max. Langenbeck, in 1849, by observing the changes in size of Purkinje's images, and fully confirmed in the same way by Cramer by his phakoidoscope. With this instrument the images of a taper-flame produced by reflection from the anterior and posterior surfaces of the crystalline lens are seen to increase in size and in their distance apart, or the reverse, according as the observed eye is directed to a distant or to a near object respectively. The corneal image, on the contrary, undergoes no change whatever, either in size or position. This change in the convexity of the crystalline lens is what is known as

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* In Porterfield's quaint language, "*The Connection betwixt our Ideas and the Motions excited in the* Retina, *Optic Nerves, and* Sensorium, *is unknown to us, and seems to depend entirely on the Will of God.*"—(II. xviii.)

† Many facts illustrate the subjective nature of vision. Dreams in sighted persons, and still more forcibly in the blind, prove the share of the mind in the act. This, so to say, memory of vision occurs to us awake or asleep. From several inquiries which I have made amongst the blind, I find that their subjective vision is as vivid as in the sighted, but that persons born blind are destitute of any such, so to say, "second" sight. However, as I am only now collecting specific information on this interesting subject, I defer saying anything more on it at present. In this point of view I might fancifully say that events are written on the tablets of the mind, as it were, with a sympathetic ink, which requires but the association of ideas—the fire—to bring out its characters. Ocular spectra (*vide* Darwin in the *Philosophical Transactions*, vol. lxxvi. p. 33, *et seq.*, and a paper by the author in the *Glasgow Medical Journal* for July 1, 1861) are further illustrations of subjective vision.

FIG. 13.

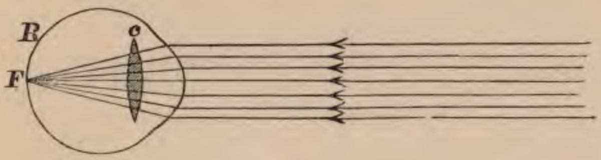

FIG. 13.—c=crystalline lens.
R=retina.

the "power of accommodation or adjustment" of the eye; or, as I shall in future term it, simply the "accommodation" of the eye. It is of great importance that you should consider this accommodation as a quantity—as a *magnitude*, in a word—susceptible of increase or diminution. This will become clear from an example. If, from having seen a distant object distinctly, I all at once transfer the eye to an object, say six inches off, and find I see *it* distinctly, it is then evident (from our previous purely optical considerations, p. 14,) that, the retina being possessed of no locomotive power backwards, the lenticular system of the eye must have increased in power. It has, in fact, increased by a quantity equivalent to a 6-inch glass convex lens. If we suppose the crystalline lens unchangeable in its power, Fig. 13 will represent the eye adapted for parallel rays (from the distant object), Fig. 14 the same eye plus a 6-inch glass convex lens placed before it. The effect of this latter is to convert the divergent rays (from the near object) into parallel ones, and these, then, will be focussed, as before, by the natural lenticular system of the eye. I have in the diagrams represented this process as if the additional glass lens were in front of the eye; really, it is as if superimposed on the anterior surface of the crystalline. Now we find in practice that the proximity up to which different eyes can accommodate themselves varies greatly in different individuals and at different ages, and even in the two eyes of the same individual. One person may read a given type as close as three inches, whilst another may not be able to read the same type closer than thirty inches. In other words, whilst the former person possesses the power of increasing the convexity of his crystalline by a quantity equivalent to a 3-inch glass lens, the second cannot increase its convexity greater than by a quantity equivalent to a 30-inch glass lens. We then say that the accommodative power of the first person is to that of the second as $\frac{1}{3}$ is to $\frac{1}{30}$, or as 10 is to 1; in other language, "the accommodation of

FIG. 14.

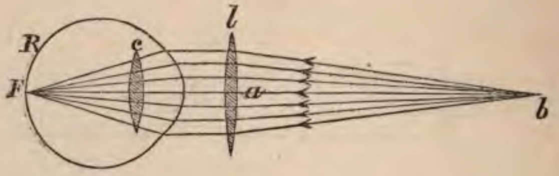

FIG. 14.—$ab=6$ inches.
c=crystalline lens.
R=retina.
l=6-inch glass convex lens.

the first *equals* $\frac{1}{8}$, that of the second *equals* $\frac{1}{30}$." The imaginary passive state of the crystalline which we have, for the sake of illustration, depicted in Figs. 13 and 14, is actually now and then met with in practice as the disease "paralysis of accommodation." This disease will be fully treated of at Chapter VIII. of the present work. To illustrate, however, what we are now discussing, I may say that in these cases the patients cannot see near objects distinctly, but we may restore their vision for them precisely in the manner delineated in Fig. 14. Such a patient to read at four inches requires a 4-inch convex glass, to read at six inches a 6-inch one, to read at nine inches a 9-inch one; and so forth I shall hereafter show you that we in atropine possess an agent capable of producing artificially this same paralysis of accommodation.*

When we, then, speak of a person possessing *e. g.*, $\frac{1}{6}$ accommodation, we simply mean he has the power of increasing the convexity of his crystalline lens by a quantity equivalent to a 6-inch convex glass lens; such a person can see critically distinctly both objects at a distance and those which are six or more inches from the eye, but he cannot see objects critically distinctly nearer than six inches. A young healthy eye is generally endowed with an accommodation of $\frac{1}{4}$ for the two eyes used together, and say of $\frac{1}{3}$ for either used alone. As an illustration of the nature of accommodation, I may mention that after a person has brought an object (*e. g.* a fine print) as close to the eye as he can possibly see it critically distinctly, he may see it equally distinctly still closer by the interposition of a convex lens—adding, in a word, an artificial amount of accommodation to what the eye intrinsically possesses.

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* This property of atropine has been long known (*vide* Müller's "Physiolog. des Gesicht-Sinnes," p. 200). Seven cases of belladonna poisoning are reported by Dr. Letheby in the *Pharmaceutical Journal* for 1846, vol. i. p. 25. Dr. Thomas Fraser has recently discovered that the Calabar bean possesses the remarkable power of contracting the pupil. Since his discovery it has been shown by Dr. Argylle, Robertson, and others, to possess a similar power over the ciliary muscle, and of thus producing an artificial spasm of accommodation. For a detailed account of the properties of the Calabar bean, *vide* an analysis of Von Gräfe's paper (in the ninth volume of the *Archiv. f. Ophth.*) in the number of the *Ophthalmic Review* for April, 1864 (p. 36).

How is the amount of accommodation measured? In the case of a normal or simply presbyopic eye, by merely ascertaining the nearest point of critically distinct vision, the "near point."* If the near point is *e. g.*, six inches, the accommodation, which we will designate by $\frac{1}{A}$, $=\frac{1}{6}$.

The consideration of accommodation in myopic and hypermetropic eyes had better be deferred till we come to treat of those diseases respectively.

In what does the *mechanism* of accommodation consist? The older observers, as Thos. Young, thought the fibres of the crystalline were muscular, and hence named it the "musculus crystallinus." But Cramer and Helmholtz have galvanized the crystalline with but negative results. Cramer thought the iris was the agent of accommodation. The image of a flame thrown on the back of the vitreous he found rendered indistinct by sending a galvanic current across the cornea; this change did not occur after division of the iris. It is now, however, the generally-received opinion that it is the ciliary muscle which is the effective agent of accommodation. Porterfield distinctly states the muscular nature of the "ligamentum ciliare," and even goes so far as to compare it to other involuntary muscles. The anatomical researches of H. Müller, Van Reeken, and Rouget go to prove that the ciliary muscle, like the iris, is composed of two sets of fibres —in man of the nonstriated, in birds of the striated variety,— a circular and a radiating. The circular fibres would by their contraction increase the convexity of the crystalline; the radiating would act as their antagonists in restoring the crystalline to its previous degree of curvature.† Has the iris any share in accommodation? I think not. The erudite author of the article "On the Optical Relations of the Eye" (in the *British and Foreign Medico-Chirurgical Review* for January, 1862) has said I have fallen into a mistake by asserting it has. Restricting the word "accommodation" to increase of refractive power of the eye, the reviewer is right. But I, in the paper he refers to,* used the word accommodation in a wider sense—that of the means of attaining distinct

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* Similarly the furthest point of critically distinct vision is termed the "far point."

† The precise mode by which this is effected is still an object of discussion. Mannhardt considers "if the iris and corpus ciliare, with its processes, are drawn back, (1) a pressure is exercised on the vitreous body, where it embraces the surfaces of the lens; (2) the zonula zinii is made tense . . . . . the fluid in the canal of Petit subjected to increased pressure, which is transmitted to the equator of the lens . . . . . . the tension of the zonula zinii prevents the lens advancing, but not its tendency to alteration of form." (Bemerkungen über den Accommodations-muskel und die Accommodation, von Dr. J. Mannhardt, in the *Archiv. f. Ophth.*, iv. i. p. 267.) Becker (Wien. Med.

Jahrb., 1863, ii. 159; 1864, i. 3) has arrived at the following conclusions from observations on four albinotic patients, in whom the iris was so transparent that the parts behind it could be observed:—1. At every age the ciliary processes are placed to the outer and anterior side of the edge of the lens. 2. Their size varies according to the size of the pupil: they increase when this dilates and diminish when it contracts. This applies to the changes in the size of the pupil, both in accommodation and under the action of atropine or Calabar bean. Wharton Jones has observed calabar to contract the pupil in an extirpated eye, and an increase in width of the space between the ciliary body and the margin of the lens. 3. As the ciliary processes enlarge during dilatation of the pupil, they pass forwards and inwards into the so-called posterior chamber, between the periphery of the iris and the anterior surface of the lens, but do not touch this structure. It follows from the above, that the ciliary processes have no direct influence in the act of accommodation. (Vide *Ophthalmic Review*, Part V., from which this summary from the pen of Mr. Windsor is taken.) It is remarkable that our eminent Dr. Mackenzie thirty years ago arrived at the same conclusion. He says (*London Medical Gazette*, vol. xiii. p. 631, January, 1834), "In some eyes after death we find the pupil small, and in others we find it large. Now, in those eyes in which we find the pupil small or contracted, we find the ciliary circle—that is, the termination of the ciliary processes around the crystalline lens, expanded . . . . in those eyes in which the pupil after death is large or dilated, we find the ciliary circle contracted."

Czermak has noticed that if, after having in the dark accommodated for the near point, he suddenly relaxed this effort, a fiery ring of considerable size appeared before him. This appearance was first observed by Purkinje, but can, according to Czermak, only be seen by few persons who possess great sensibility to such spectra, and have sufficient control over their accommodation. He regards it as an "accommodation phosphene," due to "tension of the zonula zinii and traction of the surrounding retinal ring."

* *Glasgow Medical Journal*, vol. viii. p. 268, 1860. I have here experimentally proved that a pin-hole (1) confers distinctness on objects nearer than the eye, *per se*, would be otherwise capable of accommodating for (I have since found it also corrects the disturbing influence on vision of both convex and concave lenses for near or distant objects); (2) it increases the apparent magnitude of objects.

vision generally. This meaning of the word accommodation, however, I grant, had better be abandoned, limiting its signification to increase of convexity of the crystalline. That, however, the iris does play an important part in attaining distinctness of vision I have, in the paper referred to, proved experimentally. You all know the pupil contracts when we regard near objects; dilates for distant ones. Can you for a moment imagine such a constant occurrence to be devoid of all meaning? My theory is that the iris is an *auxiliary* organ for distinct vision—that the contraction of the pupil is intended as a corrective supplement to our accommodation, properly so called, by diminishing any slight circles of diffusion in the retinal image that might possibly arise from inaccurate contraction of the ciliary muscle.

We meet with other such auxiliary agents in nature. No one doubts that we should be able to feel with the ends of the fingers without the innumerable papillæ with which they are beset; but no one either doubts that these are powerful auxiliaries in extending the fineness and range of our tactile sensibility. I beg, however, to here distinctly state, the chief muscle of accommodation is the ciliary, and that in our future studies we may almost disregard the auxiliary action of the iris. The best evidence of this are those cases of absence of the iris—either congenital or traumatic, in which accommodation remained unimpaired. A simple and convincing proof of the purely supplementary share of the iris in accommodation is, that if we place before the eye a thin plate of metal, or a card, perforated with an aperture equal to the minimum size of the natural pupil, we still retain our power of distinct vision for distant or near objects, notwithstanding we have thus altogether eliminated the action of the pupil.*

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* In the *Archiv. f. Ophthalmologie*, vol. vii. pt. 2, p. 150, Professor von Gräfe relates a case in which a partial separation of the iris having accidentally occurred in attempting to remove a prolapsus, he removed the entire iris. Afterwards the patient read No. 20 at 24 feet, No. 1 at 5¾ inches, and had an accommodation of 1-5⅔, which closely corresponded with the normal amount of accommodation of a person of his age—viz., 27 years. A four-grain solution of atropine in one hour completely paralysed all accommodation, and induced a feeble degree of hypermetropia (of 1-60th to 1-70th).

Le Cameus, Rohault, Schröder van der Kolk, and Arlt were advocates for the power of the extrinsic muscles of the eye, the recti, and obliqui, producing accommodation by elongating the axis of the globe. This hypothesis may now be all but disregarded. Von Gräfe (*Archiv. f. Ophth.*, ii.) observed the accommodation undisturbed in paralysis of all the ocular muscles.

The theory that the cornea changes its convexity is one of those traditions that, devoid of all demonstrated truth, has still retained its hold on some conservative minds. Any such change of curvature has been absolutely disproved by Helmholtz's exact observations with his ophthalmometer: this instrument would render apparent a change of $\frac{1}{200}$ of the radius of curvature of the cornea, while an accommodation for five inches demands a change of upwards of $\frac{1}{4}$ inch.*

From what has preceded you will naturally infer that after operations for cataract all accommodation is lost. Without referring further to the erroneous opinions of Arlt, I may state that Dr. Young, at the commencement of the present century, showed that any *quasi* accommodation remaining, was, in this instance, really due to the circles of diffusion being diminished by the smallness of the aperture of vision. In the paper in the *Glasgow Journal* (October, 1860, p. 272) is said:—"In the majority of these cases the patients have been able to accommodate their vision to different distances by bringing the two eyelids into such close apposition as to leave but a narrow linear aperture between them. . . . . If in such cases the eyelids be held open, and the patients be told to look through a pin-hole in a card, the same effects will ensue as from their own instinctive approximation of the eyelids." It is not uncommon to find cases of double extraction in which in one eye a portion of opaque capsule with a hole in it remains; in such cases the apparently worse eye often enjoys the best vision on this same principle. Donders has distinctly proved, what was asserted a century back by Porterfield, that after the operation for cataract not the slightest true accommodation exists.

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* Notwithstanding the above strongly expressed opinion, I may mention that whilst these sheets are going through the press, those of the fifth number of the *Ophthalmic Review* are doing so also, and that these latter contain a paper, by Dr. Henry Lawson, to prove that the cornea *is* the agent of accommodation.

Before quitting this part of our subject I must direct your attention to a point which you may find useful to remember in a subsequent part of the course. I allude to the relation which exists between the degree of accommodation and the directions of the eyes. Speaking in general terms, as indicated long ago by Porterfield* and J. Müller,† when the axes of the eyeballs converge to an object at an angle (the greater in proportion to the proximity of the object), the crystallines *necessarily* become more convex by an automatic action of the ciliary muscle consentaneous with that of the internal recti muscles; and conversely when these muscles are relaxed and the axes of the eyeballs parallel, the two ciliary muscles are also at their minimum degree of contraction.

Binocular Vision.

The pupils of the eyes are about $2\frac{1}{2}''$ apart. If we direct our eyes to a distant object, the axes of the eyeballs are practically parallel, and whether we use each eye alone successively, or the two together, in all three cases we obtain but one and the same view of the object. This may be well illustrated by performing the experiment on any tolerably distant sharply-outlined architectural projection. But if we regard a near object, the two optic axes are no longer parallel, but converge to the object at an angle larger and larger in proportion to the proximity of the object. This angle is what is termed the binocular parallax: at 12 ft. it $= 1°$; at $18''=8°$, &c., and it varies slightly with the different intervals at which the eyes are set in different individuals. A giant would have a much larger binocular parallax than an ordinary person. The consequence is that with either eye we see any near object from respectively two different points of view; the differences being proportionate to the magnitude of the binocular parallax. If we thus regard the frustum of a *solid* cone with the right eye, we see more of its right side; if with the left eye, more of its left side.

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* "Thus, when we view any Object at two Feet Distance, we not only accommodate our Eyes to that Distance, but we also move our Eyes, so as their Axes produced may meet in some Point of the Object; whence it comes to pass, that these Motions, which at first had no necessary Connection or Dependence on each other, do in time come to cohere so closely . . . . " —(Porterfield's "Treatise on the Eye," ii. p. 8. Edinb., 1759.)

† "Physiology of the Senses," translated by Baly, 1848, p. 1145.

FIG. 15.

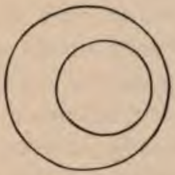
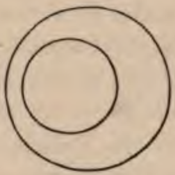


FIG. 16.



The two figures (Figs. 15, 16) represent the plane projections of the two perspectives, the lesser circles representing the summits, the greater the bases of the truncated cones; the former eccentrically approximated to each other.

FIG. 17.

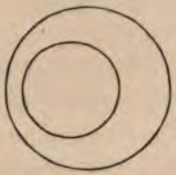
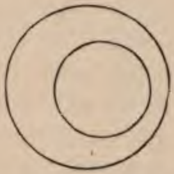


FIG. 18.



Figs. 17, 18 represent the plane projections of the frustum of a hollow cone. In these the positions of the circles representing the summits are eccentrically separated from each other.

If we present these two perspective drawings to their respective eyes separately, and then combine them by reflectors or prisms, as in Wheatstone's or Brewster's stereoscope, we get mentally reproduced the solid or hollow cones from which they were delineated.

These facts were known to Euclid more than two thousand years since; and quite clearly stated by an eminent member of our profession, Galen, one thousand five hundred years ago.

It is the mental combination of the two different perspective-projections of the object formed on the retina that conveys to us the idea of solidity. A solid differs from a plane in having a third dimension in space, which the plane has not. A square has height and breadth; a cube a third dimension, thickness. Now we estimate this thickness, visually, by the *distance* of the series of luminous points forming its extreme edges. This third dimension, distance, cannot be correctly directly estimated by one eye alone, as every one knows when he, *e. g.*, attempts to snuff a candle with one eye shut; but open both eyes and the action becomes one of certainty and precision. This is given by the muscular sense involved in the convergence of the eyeballs by the internal recti. In the same way as we, by the degree of contraction of the flexor muscles of the arm, judge of the weight of an object, do we, by the degree of contraction of the internal recti, judge of its distance.* It would be interesting to see, whether, in cases of insufficiency or paralysis of the internal recti, the power of judging of distance were in any way lost. Do persons who squint judge properly of distance?

A very singular application of this negative property of monocular vision is, that we may by closing one eye obtain a certain stereoscopic effect from a well-executed single portrait. With both eyes we at once see the whole portrait is on one and the same plane—is flat. With one eye alone we are unable to so positively recognize this fact: the consequence is that, if the geometrical perspective and the chiaroscuro be good, a considerable degree of relief is imparted by what is really a deficiency in our visual perception. Any one who has ever regarded some of the representations of relief at Versailles, or, to take a humbler illustration, some of the very artistically painted relievo letters over shop-façades, with one eye, must have been forcibly struck with this effect. If you regard a *carte de visite* portrait with one eye, and especially with the aid of a magnifying-glass, you will see a certain amount of relief imparted.*

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* An essential difference is, however, that whilst in the latter case the contraction of one set of muscles suffices, in the latter those of both sides must be called into action, at any rate, to give a perfectly accurate idea of distance. If we use only one eye, although we may acquire a certain rough idea of solidity—of relief—by the comparison of adjacent objects, still this idea is vastly inferior to that acquired by the use of both eyes.

To obtain a perfect idea of solidity both eyes must converge to the object. Brewster, ignoring the duplication of our muscular sense in this act, explains it in the following manner :—"We are now prepared to understand generally, how in binocular vision we see the difference between a picture and a statue, and between a real landscape and its representation. When we look at a picture of which nearly every part is at the same distance from the eyes, the point of convergence of the optical axes is nearly at the same distance from the eyes; but when we look at its original, whether it be a living man, a statue, or a landscape, the optical axes are converged in rapid succession upon the nose, the eyes, the ears, or upon objects in the foreground, the middle and the remote distances in the landscape, and the relative distances of all these points from the eye are instantly perceived."† You will see from this that Sir David Brewster considers the eyes judge of distance, as the muscles of the arm are sometimes used to judge of weight, when the person alternately raising the hand up and down by repeating, so to say, the weight of the body, endeavours to form a more accurate idea.

It appears to me that this is a very gratuitous hypothesis, and that all the phenomena of the stereoscope may be adequately and completely explained by the simple mental fusion of two perspectives. The only fact I know of at all supporting Brewster's hypothesis is, that if we, *e.g.*, attempt to run our eyes down the graduations of a measure, we find we can do so much more rapidly and accurately with two eyes than we can with one eye. Besides which, in the ordinary use of the stereoscope, no convergence of the optic axes takes place at all; it is supplanted by an artificial direction given to the rays of light by two prisms.

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* A series of photographs of celebrated statues is now being exhibited by the aid of the magic-lantern at the Polytechnic Institution, illustrating beautifully this effect of monocular relief.

† Brewster "On the Stereoscope," p. 51.

CHAPTER III.

PATHOLOGICAL OPTICS.

NOW that you thoroughly understand the leading optical properties of the normal eye, I may at once proceed to investigate the departures from that standard. To have attempted to do so before would have been simply to have imposed upon you a delusion. I shall, however, even now not think my time ill-spent, if I from time to time again recur to our former optical studies, when any particular defect of vision presents any unusual complication.

There are two states of the eye which we must carefully distinguish,—that in which it is directed to distant objects, its state of rest, and that in which it is accommodated for a near object. The former condition is a fixed constant one, the latter varies with every degree of convergence of the eyes. We shall therefore, with Professor Donders, propose a system of classification founded upon *the refractive condition of the eye when in a state of rest.* The following table exhibits this system:—

The Eye in a State of Rest (=crystalline at its minimum curvature; optic axes parallel).

1. Eye:—	2. Parallel rays are focussed:	3. Far-point:	4. Eye in a state of rest, adapted for:—	5. Effect of glasses for distant objects:
I. Normal	*On* the retina.	At an infinite distance.	Parallel rays.	Convexes and concaves deteriorate vision.
II. Myopic	In *front* of the retina.	At a definite distance and positive.	Divergent rays	Concaves improve vision.
III. Hypermetropic.*	*Behind* the retina.	At a definite distance and negative.	Convergent rays.	Convexes improve vision.

* The name *Hypermetropia* (adjective = hypermetropic) was introduced

The three last lines of this table, read horizontally, give the leading characteristics of each class of eye; read vertically, the leading contrasts.

I shall now discuss these three different eyes, as they present themselves to us in a *state of rest,* leaving for the present entirely out of the question the variable element *accommodation.* I shall, in other words, entirely separate the two factors, the constant and the variable, the refraction of the eye and its power of adjustment. To adopt a homely simile, if we had three different telescopes submitted to our judgment, our first business would be to test their powers of definition in regard to distant objects, as the heavenly bodies, and we might then proceed to test their individual powers of adjustment for the distinct vision of nearer objects.

The first step, then, in our investigating the refractive properties of a given eye is to eliminate the element accommodation. This may be effected in two ways. The patient may be able to suspend his accommodation by an effort of the will, or, if not, we may temporarily paralyze the ciliary muscle by a solution of atropine. For this purpose it must be of a strength of not less than four grains to the ounce; and must have had about one hour and a half given to it to act before we can feel certain that the paralysis is complete.

by Professor Donders: it is synonymous with hyperpresbyopia and hyperopia. I have retained it, not for its perspicuity, but rather the reverse, for its subtleness of expression, attaching no other meaning to it than what immediately flows from its symptoms.

CHAPTER IV.

MYOPIA.

BEFORE we can satisfactorily discuss this anomaly of refraction, it will be necessary to here introduce the subject of concave lenses. A concave lens has properties precisely the reverse of a convex one. We shall limit our observations to the case of the equi-concave glass lens, of which a sectional figure is subjoined (Fig. 19).

The two sides of such a section, *A B* and *A′ B′*, are the concave sides of two circles—the circles of curvature. *C, C′*; *C R, C′ R′*, are the centres and radii of curvature respectively. Parallel rays, *P, P′, P″, P‴*, &c., striking one surface of the lens, have a *divergence* imparted to them on their exit, *as if* they proceeded from an imaginary focus, *F*, which is called the principal focus of the lens. *F R* is the principal focal length, or briefly the focal length. It is in the case of an equi-concave glass lens, as is evident from the figure, equal to the radius of curvature, *C R*. It will be remembered that this same relation held good of the equi-*convex*-glass lens. In this last, however, the focal length is measured *forwards* from the surface of the lens, in the same direction as the rays travel

FIG. 19.

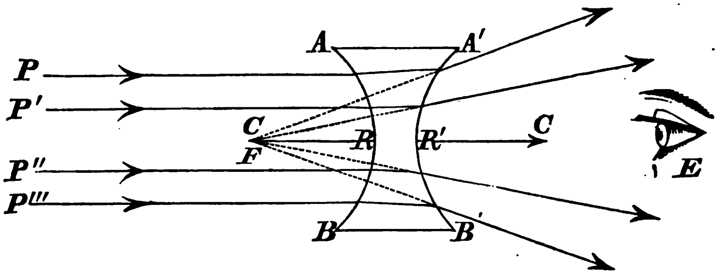
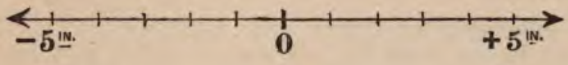


FIG. 19.—*F*=apparent focus, the dotted lines indicating the apparent path of the rays when they strike the eye, *E*.

(converge *to* their focus); whilst in the case of the concave lens the focal length is measured *backwards*, from *R* to *F*, in the contrary direction to the course the rays diverge *from* their focus. If, then, we agree to call the focal length of the convex lens positive, we must call that of the concave one negative, and such is the practice actually adopted.* We thus speak of a convex lens having, say, five inches positive focus, and a concave lens having five inches negative focus. And furthermore, from the entirely opposite properties the two classes of lens possess in every point of view, it is the usage to speak of convex lenses as positive lenses; of concave lenses as negative lenses. Or, still more briefly, employing the two algebraical symbols + (plus) and − (minus), we should designate the convex lens in question simply as a "+5 lens," the concave one as a "−5 lens;" or, as already explained, with reference to their "powers," we might call the convex one a "$+\frac{1}{5}$ lens," the concave one a "$-\frac{1}{5}$ lens." The words positive and negative are used, then, simply to express *opposite* properties. If I agree to call running forwards positive, running backwards is negative; and I might in this sense speak of having run, say, +5, or −5 miles. If we agree to call five inches measured forwards from O (Fig. 20) +5, five inches measured backwards from O are −5.

FIG. 20.



I have illustrated the meaning of these two terms perhaps a little more fully than is absolutely necessary—firstly, on account of the misconception that I know so frequently prevails on this point; and secondly, because we shall presently find a very convenient application of these terms when we come to speak of the far-point in the three classes of eyes (*vide* Table at p. 30, column 3).

If the rays of light from a luminous point are already divergent, before they strike a concave lens (rays from near objects), they will be found, after their exit from the second surface of the lens, to have acquired a still greater degree of divergence, to hence appear *as if* they proceeded from a point nearer the lens than they really do from (Fig. 21).

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* In English works on optics the reverse nomenclature prevails.

It is one of the laws of vision to refer the origin of any rays striking the eye (E) to the position a luminous point (F' in the figure) would occupy which corresponds to the degree of divergence the rays (R and R') have when they strike the eye. This luminous point or focus (F') has, then, no real existence; the rays of light have never met there; the focus is an "imaginary," "virtual," or "apparent" one, its position in space being fixed by the law of vision just mentioned. The dotted lines in both figures (19 and 21) indicate the apparent direction of the rays to the eye (E).

FIG. 21.

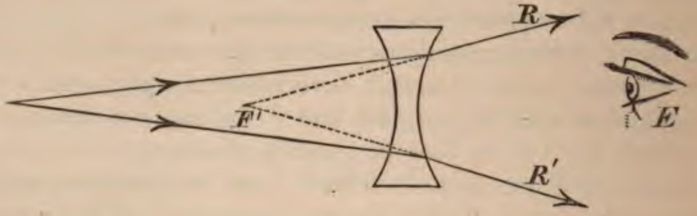


FIG. 21.—L. = Luminous point.
F' = Imaginary Focus of the Rays after their Exit from the Lens, the dotted lines indicating the apparent course of the rays.

What holds good of a pencil of rays from one luminous point of an object, equally does of all. The consequence is that a concave lens forms an apparent image of any distant object precisely at its focal length; if the object is a near one, its image appears still nearer. Furthermore, the image is always erect and diminished (Fig. 22).

There are two ready modes of ascertaining the focal length of a concave lens,—the one is to see the magnifying power of what convex lens it exactly neutralises. The positive focal length of this latter is the negative one of the concave lens in question. This method is not practically applicable to low-powered concaves. The focal length of a concave lens may be ascertained by finding out what convex lens placed in apposition with it no longer makes distant objects appear to move (or "dance," as opticians call it) as we move the pair of lenses rapidly before the eye. To illustrate this method, suppose I have a concave lens given to me, and that, when I place a 9-inch convex lens to it, and look through the pair at distant objects, I find, as I move the combination downwards, objects appear to rise, and *vice versâ*; that, on the contrary, when I place a 13-inch convex to it, the objects appear to move downwards as I move the combination downwards, and *vice versâ*; then the concave lens in question has a focal-length between 9 and 13 inches. I now try convex lenses of 10 and 12 inches, but still notice the same apparent movements of objects, though to a less degree. I then try an 11-inch convex lens, and find that objects viewed through it and my concave lens no longer execute any apparent movements at all in moving the combination, then the concave lens in question is one of 11 inches focus. In the first case (with the 9-inch and 10-inch convexes) an inverted, in the second case (with the 13-inch and 12-inch convexes) an erect image moves. This method is remarkably easy and quick in practice. The same method is applicable, *mutatis mutandis*, to convex lenses.

Fig. 22.

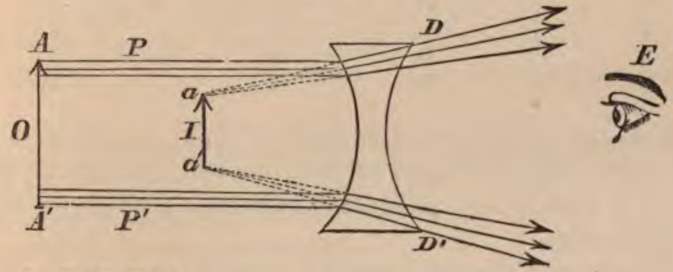


Fig. 22.—*O*=Object.
I=Image.
P, *P'*=Parallel rays from the top and bottom points (*A*, *A'*) of the object, which after emergence from the lens are changed into rays, *D*, *D'*, having a divergence as if they proceeded from *a*, *a'* of the apparent image.

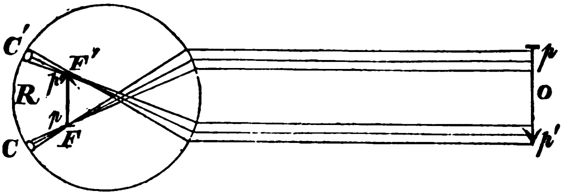
The "numbers" English opticians designate their convex spectacle-lenses by correspond with the actual focal lengths (in English inches), but the numbers they name their concaves by are arbitrary. The subjoined table (from Mackenzie) gives to what focal lengths of concaves the numbers in question correspond. I give this table for the sake of completeness, but in my practice I altogether ignore such an illogical nomenclature :—

Numbers.	Focal lengths in inches.	Numbers.	Focal lengths in inches.
1	48	7	9
2	36	8	7
3	24	9	5
4	18	10	4
5	14	11	3
6	12	12	2½

Referring to the previous table of the diagnostic signs of the three different classes of eyes, we find that the myopic one in a state of rest presents characteristics, which we shall now illustrate.

1. "*Parallel rays are focussed in front of the retina.*" This hardly needs explanation : the parallel rays from each luminous point (*p*. Fig. 23) of a distant object (*o*) are re-united (con-verged) to a corresponding luminous point (focus, *F*) in front of the retina (*R*) ; from each point the component rays of the pencil, pursuing their paths uninterruptedly onwards, re-separate (diverge) ; thus each point of the object is represented by a circle (*C*) (of diffusion), the vertical section of a cone of divergent rays, and thus; as before fully explained, vision becomes indistinct.

FIG. 23.



2. "*The far-point is at a definite distance from the eye and positive.*" The far-point is the furthest distance at which a luminous point is critically distinctly seen. It is the farthest

point which can, by the refractive power of the eye, be focussed again to a point *on* the retina. The normal eye sees critically distinctly a luminous point at *any* distance (leaving out of consideration for the present the *magnitude* a point must have to be perceptible to the eye — the minimum visibile): * the far point is therefore, in this case, indefinite or infinite. Agreeing to call lines measured from the vertex of the cornea forward positive, lines measured from the same point backward negative, the far-point in the normal eye is infinite and positive (*vide* table at p. 30, column 3). In the myopic eye the far-point is also positive, but it must be at a definite distance. This varies extremely in different cases. I have met with one case where the patient could not see any

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* Drs. Snellen and Giraud-Teulon have devised a series of test-types in which this element is taken into consideration. In each the minimum angular magnitude of distinct vision is taken as 1 mt. They are further graduated in such a manner that their numbers correspond in Paris feet to the distance at which the breadth of the thick strokes of each letter subtends the above angle on the retina. If we are dealing with a normal eye, No. I. type ought to be distinctly legible as far off as one Paris foot, XII. at twelve feet, XV. at fifteen feet, &c. If we designate by S the acuteness of vision of a person, then, in the above examples,

$$S=\frac{1}{\text{I.}}=\frac{12}{\text{XII.}}=\frac{15}{\text{XV.}}, \text{ \&c.}=1\,;$$

if, on the other hand, an eye to read I. has to approach half-a-foot to it, to read XII. three feet, to read XV. five feet, &c., then

$$S=\frac{\frac{1}{2}}{\text{I.}}=\frac{1}{2}\,;\ =\frac{3}{\text{XII.}}=\frac{1}{4}\,;\ \frac{5}{\text{XV.},}=\frac{1}{3}, \text{ \&c.,}$$

respectively. Or, if an eye at twenty feet only reads X., at fifteen feet only V., &c., then $S=\frac{1}{2}$ and $\frac{1}{3}$ respectively. S is considerably influenced by age. The following table exhibits the results of the investigation, by Dr. de Haan, of 281 cases of emmetropic eyes at different ages :—

At 10—20 years	$S=\frac{22\frac{1}{2}}{20}$
" 30 "	" $=\frac{22}{20}$
" 50 "	" $=\frac{18}{20}$
" 60 "	" $=\frac{14}{20}$
" 80 "	" $=\frac{11}{20}$

object clearly farther off than 1⅞ English inch; others, in which the far-point was at 2 inches from the cornea; and so through all distances up to 80 inches, in which last case the eye does not practically differ from a normal eye.

CASE I.—*Progressive Myopia of $\frac{1}{1\frac{7}{8}}$ unaccompanied by Staphyloma Posticum or Buphthalmos.*

Lewis M., æt. 40, consulted me, in 1862, on account of excessive myopia of his left eye. He had lost the sight of the right eye for about fourteen years. He had been in the habit of using stronger and stronger glasses, till he was at last obliged to use a combination of *two* concave glasses to assist his vision, not having been able to procure any single one sufficiently strong for his purpose. One of these concaves I found was of 2¼″ focus; the two together equivalent to one of 1¾″ focus. His eye was not unduly prominent. There was no staphyloma posticum in the left eye; the right one had a divergent squint, and was filled with innumerable brilliant floating scales, which presented a very beautiful ophthalmoscopic picture (=*synchysis scintillans*). He read with his left eye No. 1 at 1⅞ inch from the cornea—not farther, not nearer. He preferred for distance 2-inch concaves to all others, and with these read No. 23 at about 10 feet, No. 22 at 9 feet, and No. 21 at 4½ feet. Any tinting of the glasses made him see worse. I regret that I did not instillate atropine in order to determine the presence or absence of any spasm of the ciliary muscle.

High myopics require very strong concaves, and yet, when I tell you that ordinary opticians hardly ever keep glasses of a shorter focus than 6 inches, you will readily understand that there are many persons who may consider themselves practically blind from the want of sufficiently high glasses; whilst, on the other hand, many low myopics are unaware of their slight optical defect, till they feel surprised at the improvement their vision experiences from a slightly concave (such as a $\frac{1}{80}$) glass.

The first thing to ascertain in any suspected optical defect of the eye is to determine to which of the three classes of eyes it belongs. This may be ascertained, speaking generally, by placing the patient at 5—7 yards off a graduated series of types, varying from Nos. 23 to 18 of Mannhardt's and Jäger's scales,* and ascertaining his power of reading such types. If no concomitant amblyopia be present (which, however, nearly invariably co-exists in all extreme optical defects), he should be able to read No. 18. If he cannot, or even if he can, see whether a low-powered concave (*e.g.* $\frac{1}{40}$) improves vision: if so, he is myopic; or a low-powered convex (*e.g.* $\frac{1}{40}$): if so, he is hypermetropic;[*] or both deteriorate vision: if so, his refraction is normal. In instituting such an examination some precautions must be taken, to some of which we shall direct attention incidentally hereafter. Many persons fancy any low-powered glass improves their vision; this may be a mere fancy. If such suspicion exists in the mind of the Practitioner, let him hold a piece of plain glass (of which I have a piece shaped like the real lenses in my trial-case) before the eye. The patient will probably give evidence of his own delusion by declaring *it* also improves his vision. Again, in all such examinations each eye must be tested separately,[†] then the two together. I have met with five cases in which the one eye being normal the other was myopic. Cases of different degrees of myopia in the pair of eyes are quite common. Opinions vary as to the advisability of giving patients with unequal refraction of the two eyes two different lenses: I think each case must be judged on its own merits.

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* I have had a number of sheets of such types printed off; they may be had of the Secretary to the Ophthalmic Hospital, St. George's Circus, Southwark.

Having thus ascertained that a patient is myopic, our next object is to determine what particular power glass he requires. This demands the greatest care: to give him too deep a glass would entail an unnatural expenditure of accommodation for distance in order to neutralize the excess of power; to give him too low a one would deprive him of all the advantages the perfect correction of his myopia might confer. We obtain a clue to the required glass by a rough approximation to the far-point. For this purpose I in ordinary cases employ as my optometer No. 1 of Jäger's test-types. In high degrees of myopia larger types must be used, on account of the nearly constantly co-existing amblyopia. I may here mention a rather unscientific instrument that I have adapted to the purpose. I take an ordinary shoemaker's rule; the fixed upright I cut down and notch out for the reception of the patient's eye; to the sliding upright I affix three small springs, which retain in position an ordinary address-card, on to which the test-type is pasted. The fixed upright then corresponds exactly with the surface of the cornea, and by sliding along the other moveable one with the test-type attached to it, we can expeditiously find and read off the near-point, and approximatively the far-point. This little apparatus is seen at Fig. 24.

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[*] You will often find a convex or concave glass improves vision for distance, but still does not enable the patient to read any *less* type than he could before. This may depend on astigmatism or amblyopia.

[†] "As it very frequently happens that one eye has not exactly the same focal length as the other, and that, when it has, the vision by one eye is less perfect than that by the other; the picture formed by uniting a perfect with a less perfect picture, or with one of a different size, must be more imperfect than the single picture formed by one eye." (Brewster on the "Stereoscope," p. 46.)—Porterfield (vol. ii. p. 10) directs attention to the different "limits" of vision persons may have in either eye. In testing each eye separately, it is advisable for the surgeon to simply hold his hand in front of the eye not under examination; any compression of the eyeball by the patient's forcible closure of the eyelids may impede the free play of the eyeballs, and thus influence the refractive condition of the eye under examination.—*Vide* Müller's "Physiology," Baly's translation, p. 1148.

FIG. 24.

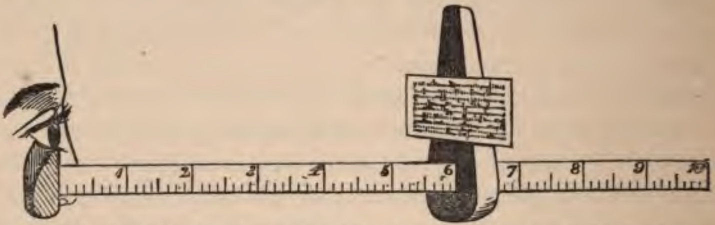

FIG. 24.—Author's optometer. The test-type is represented as exactly 6 inches from the patient's cornea. I have recently added a grooved ring at the corneal end for the reception of lenses.

Prof. v. Gräfe has proposed a set of fine wires set in a frame as an optometer; when the wires are seen singly and well-defined, vision is accurate. But in practice I find this and all such tests fail, even with educated persons, and much more so with hospital patients.

Suppose, then, you find the patient loses perfect definition of No. 1 type at 6 inches, that his farthest point of critically distinct vision is, roughly, about 6 inches, we should then, according to theory, give him for distant objects a concave glass of 5½ inches focal length (the glass being ½ inch from the cornea); for then we should present to the eye an image of the distant object exactly (6 inches from his cornea) at his extreme limit of distinct vision. But practice teaches us that even a 6-inch concave would be too strong a glass for distance; he will probably require a 7- or an 8-inch one: which of these, we must find out by trial.* Now, what does this apparent contradiction between theory and practice arise from? From two circumstances, viz.:—1. The associated action of the internal recti and ciliary muscles. Parallelism of the eyeballs corresponds with relaxation of these muscles, convergence with their contraction. Now, when we tried our patient with the test-type with his naked eyes, these converged to a point 6 inches off—the ciliary muscles acting consentaneously increased slightly the convexity of his crystalline lenses—increased their power. But when, with concave glasses on, the patient regards distant objects, the consequent parallelism of the eyeballs is associated with a corresponding relaxation of the ciliary muscles—a diminution of power of the crystallines; the concave glasses must, therefore, be of longer focal length than the found far-point, they no longer having any accommodation to neutralize. And 2. From the letters of the type not being, perhaps, distinctly recognizable farther than 6 inches, on account of the diminution in their angular magnitudes.†

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* This trial may be facilitated by an ingenious adaptation, by Prof. von Gräfe, of the Galilean telescope to optometric purposes. In this instrument, when the eye-piece and object-glass are separated by a distance equal to the difference of their focal lengths, the rays emergent from the system are parallel; if this distance be diminished, divergent; if increased, convergent. On the body of this optometer the different degrees of myopia or hypermetropia respectively are marked off corresponding to different degrees of separation of the eye-piece and object-glass. The physical and psychical fatigue and confusion involved in the repeated apposition and comparison of various trial glasses to the eye are thus avoided; but, at the same time, I must add that the results I have obtained from von Gräfe's instrument were often fallacious.

† Prof. von Gräfe states, that in myopics (not simultaneously affected with weakness of the internal recti) the *power* of the internal recti increases with age, so that they can reach their far-point under a considerable convergence

The *rationale* of the action of a concave glass in myopic patients was at one time a matter of extreme difficulty to me. The knot I found cut by authors by two views—(1) that the concave glass substitutes for a distant object its virtual image at the patient's farthest point of distinct vision; (2) that it simply increases the divergence of the rays, leaving the locality of the object unchanged. Both explanations are as confused, as they are unsatisfactory. Of the following experiments, I believe the second one to be original; if not so, it is certainly but little known:—1° view any object, such as a candle-flame, through a deep concave glass (or an inverted opera-glass), it appears diminished and much farther off than it really is. This is owing to our mental association of diminution of size (an inherent effect of the concave glass) with distance. But 2° view the object with either eye in such a way as to see it simultaneously both *through* and *not through* the concave lens, we then at once perceive the object at its real distance from the eye, its image at a distance from the lens exactly equal to the focal length of this latter.* To a myopic person with his proper reducing glasses all distant objects appear in their real positions (to high myopics, who have never before worn glasses, objects often at first appear further off than they really are); but if the myopic patient with either eye regards, as in 2°, an object at the same time *through* and *not through* his reducing glass, then he at once perceives the

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of the optic axes, which convergence does not imply any *exertion* of the recti. As far as my observation goes, I cannot agree with the learned professor on this point, my experience all tending to corroborate the views expounded in the text.

* The simultaneous perception of the real position of the object with its image destroys the mental illusion that refers this latter to the presumed situation of the object. I may say that Mr. Parkinson, of Cambridge, to whom I submitted this theory, quite coincides with my views on the subject. A similar mental illusion is the "conversion" of a *bas*-into a *haut*-relief, according to the way in which the light falls on an intaglio (or cameo).—*Vide* Brewster's "Natural Magic," p. 98, *et seq.* The observation "2°" in the text explains, I think, certain cases of *monocular* diplopia, due probably to differences of refractive power in different parts of the optical constituents of the globe. I have thus recently observed a very marked case of monocular diplopia in a case of partial dislocation of the lens.

object in its real position, but its image formed exactly at the focal length of the concave glass.

These simple experiments prove that the myopic eye with its reducing concave really sees the virtual images of distant objects at the focal length of the glass; but *mentally refers them to their true planes of situation.* Were it not for this faculty of the mind, the concave glasses would confuse their wearers much more than they assisted them.

Professor Donders has proposed a convenient nomenclature for different degrees of myopia, viz., naming them by the *powers* of their respective reducing glasses. In this way we speak of a person having a myopia of $\frac{1}{2}$, another of $\frac{1}{4}$, a third of $\frac{1}{12}$, &c. The advantage of this system is, that these fractions, by their intrinsic value, express the *degrees* of the myopia, which 2, 4, 12, &c. (the *focal lengths* of the glasses) would not do.

Having accurately corrected the myopia of a patient by his reducing glasses, have we practically transformed the eye into a normal one? By no means. In the first place (as we shall hereafter advert to), most myopic eyes are essentially diseased ones. Secondly, all concave glasses diminish more or less—the virtual images presented by the glass to the eye appear less than their respective objects. The virtual image of a distant object has a less angular magnitude at the optical centre of the eye, than the object itself has at the same point. But for retinal images (in the case before us the image of an image) to convey to the mind defined impressions, they must not be under a certain magnitude; in plain language, there are many objects so small that no one can see them beyond a certain distance, or even at any distance, ever so near the eye.* When we are dealing with low degrees of myopia, such as $\frac{1}{20}$, $\frac{1}{14}$, $\frac{1}{10}$, &c., the diminishing property of concave glasses is attended with no inconvenience; but as soon as we arrive at high degrees, such as $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{3}$, or $\frac{1}{2}$, &c., we find that no glasses, at any rate, at first, however accurately chosen, will enable the patient to read a moderately small type, such as 19 or 18, at any considerable distance; but that for each of the types from 23 to 18 he must approach nearer and nearer to the type in proportion to its smallness.

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* Dr. Hook estimated the *minimum visibile* as comprised in an angle of 1 minute, as is assumed in Giraud-Teulon's and Dr. Snellen's test-types.

Another remarkable circumstance affecting the application of reducing glasses to high myopics is, that these patients invariably complain of a peculiar "dazzling" appearance the very deep glasses confer on objects. So disagreeable is this sensation, that such patients invariably prefer lower glasses to those which completely neutralize their myopia; in other words, they prefer sacrificing definition in order to rid themselves of this annoying feeling. Donders (*Archiv f. Ophthalmologie*, vol. iv. part 1, page 312) has also noticed the fact, but does not appear to have further inquired either into its cause or its remedy. I at first thought it depended on the back (ocular) aspect of the deep concave glass in its capacity of a concave mirror reflecting side-light on to the eye; but I found that covering this back with a dead-black paper, leaving only a central aperture for vision, had no remedial effect on the "dazzling." I have, however, succeeded in finding the remedy: it consists simply in tinting the glass.* This appears to me to prove that the sensation alluded to has its origin in some hyperæsthetic condition of the retina to light. The only direct evidence I have to advance in favour of this hypothesis is, that I have never seen any of the highest degrees of myopia unaccompanied by morbid alterations of the fundus oculi (staphyloma postic.) but once; and in this instance, given at p. 38 —a myopia of $\frac{1}{1\frac{7}{8}}$—the patient wore a 2-inch uncoloured concave glass without any inconvenience.

On the other hand, it is but fair to say, I have seen a few cases of high degrees of myopia, accompanied by extensive staphyloma posticum, in which the reducing glasses did not dazzle the patient.

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* The most convenient method of applying this principle is joining a piece of plane tinted glass with Canada balsam to the back of a plano-concave lens. If a double concave lens is simply manufactured out of a piece of tinted glass, the varying thickness of the glass is accompanied with a varying degree of intensity of tint, besides the unpleasant conspicuousness of the depth of colour of the extreme margin of the glass. Messrs. Murray & Heath have suggested that this difficulty may be obviated by grinding the unused circumference of the lens down to a thin flat surface.

CASE II.

Lady B., æt. 63, consulted me on June 26th, 1862. *Vision:* left eye too amblyopic to have any useful sight; right eye, read No. 1 between 2¾" and 2⅜", so that her accommodation was about $\frac{1}{17}$. With a 3-inch concave she read the larger of Jäger's types at distance with her left eye, in which a well-defined large external staphyloma posticum was seen. She said the 3-inch glass did not "dazzle" her, that tinting made the light "softer," but that she, on the whole, preferred it not tinted.

I have thus succeeded in solving what I think will be allowed to be an important practical problem—that of enabling high myopics to avail themselves of all the advantages of the perfect definition their actual reducing glasses can give, without at the same time their being annoyed by this disagreeable "dazzling." *

CASE III.—*Myopia of $\frac{1}{3\frac{1}{4}}$.—Impossibility of wearing the reducing glasses on account of their "dazzling."—This remedied by tinting the glasses.*

Jane F., æt. 25, consulted me on January 15th, 1862. I found that at about 15 feet she could not read No. 23, that the far-point for the right eye was, for No. 1 2¾", for the left eye the same; whilst the near-points for both eyes were respectively 2¼" and 2¾"; so that she practically possessed no accommodation. In each fundus oculi an extensive external staphyl. postic. was seen. The globes were full and prominent. With 3¼-inch concaves she read Nos. 23 and 22 at distance quite distinctly, but was obliged to put up with 5-inch concaves, which did not enable her to see so far off, on account of the distressing dazzling sensation the 3¼-inch glasses caused her. This was the first case I tried the effect of tinting the glasses in, and on seeing her three months afterwards, she said she had constantly worn her tinted 3¼-inch glasses —I verified their focal lengths—without ever again experiencing the "dazzling" sensation they, before being tinted, caused. In these cases we may sometimes with advantage substitute for a deep concave glass a more shallow one, in combination with a stenopæic apparatus: the effects are a larger, equally defined image with a diminution of the amount of light.

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* My opticians, Messrs. Murray & Heath, inform me that they are now constantly in the habit of adopting this plan with the most marked success.

convex lens, for the far-point $b=5\frac{3}{8}''$, for the near-point $b=2\frac{3}{8}''$, k being in both cases$=\frac{1}{2}''$. Therefore—

$$\beta=\frac{5\frac{3}{8}\times 12}{5\frac{3}{8}-12}=-\frac{516}{53}=-9{\cdot}7'';$$

adding $\frac{1}{2}''$ to this, my far-point $(=r)$ would be $10{\cdot}2''$: the reducing glass of my myopia is, as previously ascertained, $\frac{1}{10}$. Similarly I deduce, using the same auxiliary lens, my near-point (p) to be $3{\cdot}4''$, and without it$=3{\cdot}4''$.

Suppose, now, we find that a person who uses 7-inch concaves for distance has an accommodation of $\frac{1}{12}$; to see distinctly at 12 inches the patient will, with his reducing glasses on, have to use his entire accommodation. But such a procedure would soon so exhaust the ciliary muscle as to lead to all those symptoms of fatigue of the eye which we shall hereafter fully enter into under the head of "Asthenopia." If we give the patient for reading, working, &c., at 12 inches, a pair of 17-inch concaves $(\frac{1}{7}-\frac{1}{12}=\frac{1}{17})$, he will for 12 inches have no occasion to use his accommodation at all, but will have a certain useful range of vision both beyond and on this side of 12 inches. I must here distinctly confess that these calculations must all be controlled by actual clinical experience. As far as rules can be laid down, I have endeavoured to do so. These are—

1. If *little or no* accommodation exists, give a glass which entirely supplants any slight natural accommodation still present.

2. If a *moderate* amount of accommodation exists, give a glass which *partially* supplants this natural accommodation.

3. If *perfect* accommodation exists, the same glass that does for distant will do for near objects.

Is it possible to diagnose a case of myopia altogether independently of any subjective symptoms? It is. Most patients present unusually large eye-balls: this is rendered most obvious when the person looks as far as he can to the side. The great length of the antero-posterior axis * and the general fulness of the globe then become very apparent.

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* "Nimia oculi longitudo facit myopiam." (Boerhaave's "Prælect. de Morb. Ocul." Götting. 1746, p. 174.)

One of the heirlooms of traditional Surgery is the supposed undue prominence of the cornea in myopia. Helmholtz and Donders have distinctly disproved the general truth of this statement by laborious measurements of the cornea by the ophthalmometer. A second set of very diagnostic symptoms are those furnished by the ophthalmoscope.* These are the possibility of seeing the inverted image of the fundus oculi without the use of an objective—: myopic refraction. This of itself is very strong presumptive evidence of (a high degree of) myopia. But to obtain a sufficiently extensive field of view, it is better to employ the ordinary objective—a lower one than is used for normal eyes. A very characteristic appearance is then usually seen. Embracing the optic papilla is a crescentic pale or white patch. It varies greatly in extent, being sometimes very narrow, sometimes very broad; generally situate between the optic papilla and yellow spot, not unfrequently, however, entirely surrounding the papilla. The retinal vessels coursing over the white patch are seen unusually well by reason of the contrast between their red colour and the subjacent white ground, and often pursue an unusually straight course. The "crescent," or staphyloma posticum, as it is called, is mostly well defined, often very abruptly so, and not uncommonly bordered with a punctuated line of black pigment.†

"Myopic refraction" may be considered pathognomonic of myopia; a staphyloma posticum almost so. Surgeons in military practice, more especially on the Continent, may be called upon to decide the question of the existence or not of myopia: in the event of prevarication on the part of the person under examination, the ophthalmoscopic tests of myopia will prove most valuable and decisive. Even in civil practice, these tests are sometimes of great utility. Hysterical simulation or dissimulation of ametropia I have met with on more than one occasion.

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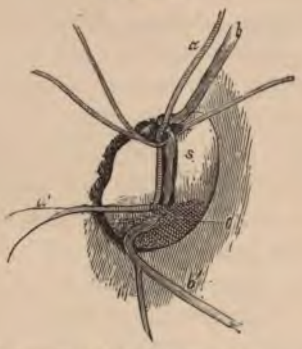
* For further information on this point consult the admirable edition of "Zander on the Ophthalmoscope," by R. B. Carter, of Stroud.

† I have notes of sixty cases of myopia which I have examined with the ophthalmoscope. In forty-four of these staphyloma posticum was present; in thirty-five it is noted as being at that side of the papilla which is towards the macula lutea, whilst in five cases only was it exclusively to the inner side, in one only exclusively above. In nine cases no staphyloma posticum existed. In addit[illegible] staphyloma posticum, I have in nearly all extreme cases of [illegible] the optic entrance either ill-defined, deformed, atrophi[illegible]. The inner tissues of the eye, too, in such cases n[illegible] appearance of tension and thinning of the choroid [illegible] much more numerous and less in calibr[illegible]

In one case I observed the staphyloma was fringed outwardly by a peculiar halo of regular short lines. In another rare case I observed the staphyloma was excavated—was in fact a staphyloma posticum in the true sense of the word.

It occurred in a woman æt. 38. She had a myopia of $\frac{1}{9}$ in each eye, and possessed an acuteness of vision of about $\frac{1}{10}$. I give a woodcut (Fig. 25) of the inverted image of the staphyloma posticum of the right eye.

Fig. 25.



S =Excavated staphyloma posticum.
a =An artery pressing over the bent vein, *b*.
b'=A second bent vein.
O=Deformed and atrophied optic papilla.

Sometimes, however, the crescent merges gradually into the surrounding redness of the fundus, and is in cases of extreme myopia not unfrequently accompanied by other isolated irregular white patches, intermingled with black pigment spots. V. Gräfe considers all these appearances as due to a diffused sclerotico-choroiditis, which, according to Follin, assumes an atrophic tendency in the involved tissues. Those myopic eyes which have been anatomically examined have generally displayed a marked elongation of the globe, especially so in the posterior hemisphere—hence the other name which has been applied to this peculiar pathological condition, viz., staphyloma posticum.* I have met with a few cases of myopia, one of the highest degree I ever saw ($\frac{1}{18}$th) in which no such staphyloma existed. In these it is fair to assume the myopia was caused by some abnormal refractive condition of the humours.

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* The first anatomical description of staphyloma posticum is to be found in Scarpa's Treatise (translated by Briggs, 2nd edit. p. 399). In one of two dissections he found "there was a deficiency of the nervous expansion of the retina within the cavity of the staphyloma; that the choroid coat was

A form of apparent myopia, of which I have seen several instances, is one which I, with my friend, Dr. Giraud-Teulon, consider produced by a spastic state of the ciliary muscle. This "functional myopia" (?) yields on atropine to emmetropia, or even hypermetropia; or to a lower degree of myopia, to which it is a superadded factor. This form of short-sight is generally very slight and has been observed by me principally in patients who were also presbyopic.

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very thin and discoloured at this part, and wanted its usual vascular plexus; and that the sclerotica, particularly at the apex of the staphyloma, was rendered so thin as scarcely to equal the thickness of writing paper." The predisposition to staphyloma posticum in the position it always constantly occupies is probably due to its being that of the protuberantia scleræ fœtalis (v. Ammon), where the sclerotic, even at birth, is thinner than elsewhere.

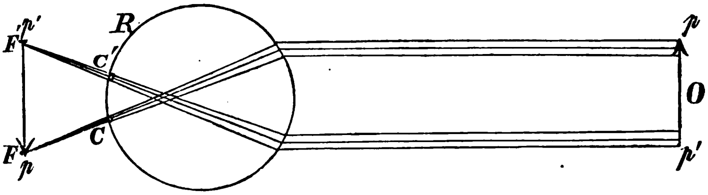
CHAPTER V.

HYPERMETROPIA.

THE two chief anomalies of refraction the eye is subject to are myopia and hypermetropia.* The former we have discussed at some length; the latter it will now be our task to inquire into, and in doing so I shall, as in the case of myopia, follow the table of diagnostic signs (p. 30) of the eye in a *state of rest*. In *Hypermetropia* :—

(1.) *"Parallel rays are focussed behind the retina."*—

FIG. 26.



Parallel rays (Fig. 26) from each luminous point (*p*) of a distant object (*O*) tend to a focus (*F*) behind the retina (*R*);

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* The following quotations on the history of this defect of vision may not be devoid of interest. Donders (*Archiv f. Ophthalm.*, vi. 1, 1860) says :—"Hypermetropia has, up to the present time, been very little studied: the older oculists either knew it not or misunderstood it. . . . . . . The ignorance on this important defect was universal. . . . . . Even by Ruete (1845) was its existence not known." I here, however, distinctly assert that Mackenzie, in his "Physiology of Vision," p. 150, published in 1841, gives a clear definition of the disease: "but there are instances of the eye being so flat as to require convex glasses to converge even parallel rays to the retina, which is equivalent to a power of bringing convergent rays to a focus." However, no unprejudiced person can rise from the perusal of Professor Donders' admirable exposition of the anomalies of refraction and accommodation of the eye without being impressed with the importance of his researches,—the truly philosophical spirit in which they have been conducted.

if we imagine the tunics of the back of the eye removed, a distinct image of (*p*) would be formed behind the retina, at (*F*). As it is, however, every luminous point (*p*) of the object is reproduced on the retina as a circle of diffusion (*C*), and hence no distinct image of a distant object is formed on the retina.

Thus, a hypermetropic eye is deficient in its converging power on the rays of light. As an illustration, I may say that after operations for cataract, the share the crystalline lens takes in this converging power being lost, the eye becomes hypermetropic.

Again, we may artificially convert a normal eye into a hypermetropic one by placing before it a concave lens; a myopic eye into a hypermetropic one by placing before it a concave lens stronger than is necessary to neutralize its myopia. But, as we shall hereafter see, by far the greater number of hypermetropic eyes met with in practice are the result of a congenital conformation of the globe.

(2) "*The hypermetropic eye in a state of rest is adapted for convergent rays.*"—Although, as we have just seen, the hypermetropic eye has too low a converging power to focus parallel (and *à fortiori* divergent) rays on to the retina, you can readily understand that it may have sufficient to focus rays which are already in a state of convergence before they strike the cornea. Now, as I have before said, the only two classes of rays met with in nature are parallel and divergent ones; but we may confer on either of these any desired amount of convergence by receiving them on a suitable convex lens. Hence the remedy for hypermetropia is a convex lens of such a power as to give the incident rays from objects a sufficient degree of preliminary convergence before they strike the cornea as to enable the eye to effect the additional amount of convergence necessary for the production of a defined, distinct image on the retina.

(3.) "*The far-point of a hypermetropic eye in a state of rest is at a finite distance* (*from the eye*), *and negative.*"—In the normal eye in a state of rest, the focus (luminous point) of rays which, striking the cornea, will be reunited to a focus on the retina, is, as we have seen, positive and infinite, in the myopic eye positive and finite. In the hypermetropic eye rays of light to be brought to a focus on the retina must, before they strike the cornea, in the first instance (by a convex lens held before the eye) be made to tend to (converge to) a focus behind the retina. The higher the power of this convex lens the higher the degree of hypermetropia, whilst, when this power is $\frac{1}{50}$, or less, the eye closely approximates to the normal one. Measuring the focus of these convergent rays from the cornea backwards, we may by a figure of speech (in analogy to the far-points of normal and myopic eyes), say that in the hypermetropic eye the far-point is finite and negative.

The *amount* of deficient converging power of the hypermetropic eye—the amount of hypermetropia—is given by the convex lens necessary to produce distinct vision of distant objects. The power of this lens may vary from $\frac{1}{50}$ up to $\frac{1}{3}$; at least this last is the highest degree I have ever seen (in a student at Utrecht),* excepting, of course, a hypermetropic condition of the eye dependent on a cataract operation or a congenital deficiency of the crystalline.

The following is the highest degree of hypermetropia I have ever seen in my own practice.

CASE IV.

John Edwards was 6 years old when he was brought to me at the Ophthalmic Hospital, Southwark, by his mother, on December 12th, 1860. Since the child was three years old she had observed his sight was defective, and that he always brought objects very close to his eyes when he wished to see them distinctly. I found he required 5-inch convexes to read No. 22 at distance; but after the eyes had been subjected to atropine for an hour he required 3½-inch convexes, with which he read No. 23 at 6 feet 9″. I re-examined his eyes about twelve hours later, and found 5-inch convexes were the glasses with which he obtained the most distinct vision for distance, reading with them No. 21. On examining his eyes ophthalmoscopically, no morbid appearances were perceptible in either fundus oculi; but I could observe the direct image in either eye as far off as 3 inches from the cornea, after the full action of atropine. Both catoptric images from the lens-surfaces could be distinctly seen in each eye, proving it was not a case of congenital absence of the crystalline lenses. I saw the case again upwards of a year afterwards; the boy ever since I first saw him wore 5-inch convexes. With these he read at 20 feet No. 21, without them he could not read No. 23.

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* It is a case mentioned by Donders, at p. 241 of his work on the "Anomalies of Accommodation and Refraction."

The following are the outlines of two other cases of unusually high degrees of hypermetropia.

CASE V.

Sarah W., æt. 8, was brought to the hospital on account of her "short sight"—she was always obliged to hold things very close to her eyes to see them—and her inability to read, &c., for longer than a few minutes together. She had also been observed to squint, a fact which I myself observed in either eye momentarily, but decidedly, when she looked intently at a near or distant object. The eyeballs appeared very small; the cornea measured 5‴ in diameter; the palpebral apertures only 8‴ in length; the pupils in a full light measured 1‴ and acted well. With the *right* eye she could not read *C C* (Snellen) beyond 10′; with a 4-inch convex, LXX. at 20′, and the same type with the same glass after two hours' application of a strong solution of atropine (gr. viii. ad ℥j). The *left* eye was quite similar in its refraction, excepting that after atropine she preferred a 3½″ convex. This was, however, not a case of uncomplicated hypermetropia, as the ophthalmoscope showed. The optic entrances were only recognisable by the confluence of the retinal vessels, which were, at parts, much obscured. In the left fundus some pale, irregular spots, with slightly pigmented deposits, were observed. The direct image in each eye was well seen at 7—8″ off without any ocular; at 1″—2″ a 12-inch convex ocular was necessary. From the above it follows that part of the amblyopia was owing to some chronic retinal and choroidal processes.

CASE VI.

Henry N., æt. 10.—His sight had been defective as early as he could remember, having been unable to see either near or distant objects well. He had been repeatedly very severely punished by his father, who thought he was malingering at school; but an inspector of schools, who believed in the reality of his defective vision, advised him to go to the hospital to have his eyes examined. I found a manifest hypermetropia of $\frac{1}{10}$, and a total of $\frac{1}{4}$, with an acuteness of vision of $\frac{1}{4}$. Ophthalmoscopically I detected nothing morbid, but slightly egg-shaped optic entrances. He said he saw horizontal lines better than vertical ones. But I found him so unintelligent as to render any exact determination of his astigmatism practically impossible.

derstand, the eye has within itself

an intrinsic power of increasing its converging action (in the crystalline). The normal eye has no occasion to exercise this function for distant objects, and therefore it remains in a state of rest. The myopic eye is already abnormally excessive in its converging power, and would therefore, if it could, rather diminish, than increase the convexity of its crystalline.

But, as you might *à priori* have expected, the hypermetropic eye accommodates even for distance, abnormally using a function for distance which a normal or myopic eye only employs for near objects. It in this way avails itself of its power of accommodation to supplement its defective power of refraction. Such an eye is then "never in a state of rest" in the sense we have used this expression. Have we any means of reducing the eye to such a state, and by thus eliminating the element accommodation, estimating the total amount of deficient converging power—of hypermetropia—present? We have: by paralysing the ciliary muscle by the instillation of a solution of atropine.*

The preceding will become intelligible from an actual example. A young woman required a 40-inch convex glass for the distinct perception of distant objects; after instillation of atropine she could, with the naked eye, hardly see distant objects at all, but could so perfectly with an 8-inch glass. In the first instance her hypermetropia was neutralized by two factors, (1) the $\frac{1}{40}$ convex lens, (2) the increased curvature she herself gave her crystalline lens by contraction of the ciliary muscle—by her accommodation, in a word; in the second instance we destroyed this last factor by atropine, and *then* we found she required, instead of a 40-inch, an 8-inch convex glass. Therefore, she previously accommodated by a quantity equivalent to the difference between these two glasses, viz., a 10-inch glass: $\frac{1}{8}-\frac{1}{40}=\frac{1}{10}$. The *total* hypermetropia of such a case is $\frac{1}{8}$, the *latent* $\frac{1}{10}$, the *apparent* or *manifest* $\frac{1}{40}$. There are several circumstances which may lead to the suspicion of hypermetropia; by a low-powered convex glass either improving, or, at any rate, not deteriorating vision for distance, as it would in a normal or myopic eye. In applying this test you must allow the patient to try the glass on for a few minutes, as he has so accustomed himself to accommodate for distance, that he cannot for the moment relax even the very slight fraction of this effort, which the lowest powered convex glass is intended to supplant.* Convergent strabismus and asthenopia are commonly associated with hypermetropia (*vide* Cap. X.). An abnormally distant position of the near point in a young subject is highly indicative of hypermetropia. Such cases are often misunderstood as "singular instances of presbyopia in young subjects." Their rationale is evidently that the patient using a great part of his accommodation to neutralize his hypermetropia, has a proportionately small part remaining over available for its legitimate purpose of neutralizing the divergence of the rays from near objects. A highly-interesting test of myopia or hypermetropia is afforded by the unequal refrangibility of the different coloured rays of the solar spectrum. Many dark violet (or cobalt-blue) stained glasses only permit the blue and red rays of light to pass through them—the highest and least refrangible rays of the spectrum. If a moderately myopic eye regards the flame of a candle or of gas through such a glass, the red rays will be nearly focussed on the retina, whilst the blue ones form large circles of diffusion on that structure; the consequence is such a flame appears to the myopic eye *violet-red, surrounded by a blue margin.* To a hypermetropic eye the flame appears *reddish-blue surrounded by a red margin.*

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* As I shall later have occasion to advert to at length, with advancing age our faculty of accommodation diminishes: in old presbyopic subjects this precaution is therefore unnecessary. I may, however, here state I consider even in myopia, with a fair amount of accommodation, it is advisable to first paralyse the accommodation by atropine before determining the reducing glass, as I find patients frequently on first trial prefer too high glasses, and might thus by their use acquire a hypermetropic accommodation, which would necessarily lead to diminution of their normal accommodation and consequent asthenopia. My observations agree with those of Professor Donders, who has, in a tabular view he gives of the relative range of accommodation of the myopic eye, pointed out its excessive positive value for low degrees of convergence of the eyeballs (for distant objects), and the total absence of negative value—so that myopic patients possess no power at all of overcoming the weakest convex glasses for distance. For further information on this interesting subject, vide *Arch f. Ophthalm.* vi. 1.

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* Many asthenopic patients possess such powers of accommodation that they can read as small a print as No. 16 at a considerable distance. This is, however, no proof of the absence of hypermetropia; this can only be inferred by a convex glass not improving vision for distance, *after the instillation of atropine.* I may here remark that in this way normal eyes may become very slightly hypermetropic, probably from the atropine destroying the tonicity of the ciliary muscle, and I think I have similarly observed myopia somewhat decreased by the same agent. Of 86 cases of hypermetropia, 38 were males, 48 females; whilst of 50 cases of myopia the numbers of either sex were precisely equal. This preponderance of the female sex in hypermetropia is probably more apparent than real. The patients were principally hospital ones, and of these the occupations of females would be more likely to cause them to feel inconvenience from asthenopia (depending on hypermetropia) than those of males would.

How do we determine what glass is required to neutralize the hypermetropia? As far as I know, this is a mere matter of trial. In the practical treatment of a case you must not at once prescribe this neutralizing glass, but begin with the highest that improves vision for distance, before the eye has been subjected to the action of atropine.* For you must remember accommodation for distance has become an instinctive habit, not to be broken by any such rude violence. You will find, if you watch a case, that after a time this habit gives way, and thus by degrees you will have to increase the power of the glasses the patient wears, till such ones are at last reached which completely neutralize the entire hypermetropia present. As in myopia, each eye must be examined separately, and then the two together. Thus, in a case I found one eye had a hypermetropia of $\frac{1}{6}$, the other of $\frac{1}{14}$; whilst, in three cases, one eye was normal whilst the other was hypermetropic.

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* However, I have met with cases where the hypermetropic state of the eye was not demonstrable before the action of atropine, so strongly ingrained had become the habit of accommodating for distance. In one case a young woman read with her naked eyes No. 16 easily at 20 feet! Yet atropine revealed an hypermetropia of $\frac{1}{8}$! In some cases hypermetropic patients, before atropine has been instillated, even assert that their vision is improved by *concave* glasses. These, of course, add to their hypermetropia, but apparently improve their vision by stimulating them to an extra amount of accommodation, not only sufficient to overcome this superadded artificial hypermetropia, but to still further correct their inherent hypermetropia. Donders thinks the apparent improvement of vision is due to the patient's preferring the smaller retinal images induced by the concave glasses (?). As an example I may quote the case of a young woman, 16 years old, who suffered from asthenopic symptoms, and declared, before atropine was applied to her eyes, her vision for distance was improved by 24-inch *concaves;* but after atropine, actually required 18-inch *convexes* to read the type she read before atropine. Such cases, of which we must be on our guard, are cases of the so-called "spasm of accommodation."

The question, in how far glasses for distance are available for near objects, depends (1) on the total amount of accommodation the patient possesses, and (2) on how much of this he habitually expends in the neutralization of his hypermetropia. This is practically determined thus:—Let the patient (his eyes not being under the influence of atropine) have on the strongest convex glasses he can bear for distant objects; then find with these glasses on the nearest point of distinct vision of a small type. If this distance varies anywhere between 9—5, or less inches, he has a fair amount of accommodation still at his disposal for its legitimate object (the neutralization of the divergence of the rays), and he may use the same glasses for near, as for distant objects. But if the patient's near-point with his distance-glasses on is, say, 20 inches, he has only $\frac{1}{20}$ accommodation at his disposal for the purposes of reading, writing, &c. Let the distance-glasses, *e.g.*, be $\frac{1}{15}$ power; then with glasses of 7 inches focus ($\frac{1}{15}+\frac{1}{8}-\frac{1}{20}=\frac{1}{7}$) the person will be able to read, &c., at 8 inches by using all his accommodation, and at such convenient distances as 10, 11, or 12 inches by only a partial expenditure of that function.

No one could *à priori* form any conception how common a disease hypermetropia is. In 166 cases of abnormal refraction of the eye, I find 80 of myopia and 86 of hypermetropia. The truth is, many of these latter pass unrecognized, and some of the higher degrees are mistaken for enigmatical cases of myopia, as the patients not uncommonly hold objects close to the eye to see them distinctly, and yet are not only not improved, but actually made worse, by a concave glass. They do this, I think, to correct the defective refraction of the eye by the consentaneous contraction of the pupil. If you make your own eye artificially hypermetropic by a concave glass, you will find your sight considerably impaired, but may at once restore it by a pin-hole aperture, the rationale of which has already been explained.* Donders thinks these patients seek to increase their accommodation by increasing the convergence of the optic axes, but seems to ignore the simultaneous, greatly-increased ratio the divergence of the rays acquires by this approximation of the object.

Independent of the above subjective symptoms, there is a diagnostic objective one of the presence of hypermetropia. The direct image of the fundus oculi may, if the observer's own eye be normal or myopic, be seen without any concave eye-piece. In 45 cases of which I possess ophthalmoscopic notes, I find in 32 the fundus oculi was perfectly normal; in 8 next the optic entrance was a narrow black pigment line; and in 4 cases a staphyl. post. was observed, not distinguishable from that so generally met with in myopia. As the eyes of myopic patients are often fuller than natural, so those of hypermetropic ones are more sunken and less.

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* The same holds good for the disturbing influence of a convex glass.

CHAPTER VI.

ASTIGMATISM.

IF, for the sake of precision, we call the centre of the cornea the anterior pole of the eyeball, the corresponding point at the back of the globe its posterior pole, then a circle passing through both poles is a "meridian."* In general, it was assumed that all the meridians of the cornea were circles of equal curvature, and that, consequently, the cornea refracted equally in all its meridians. Such, however, is not strictly the fact. The cornea has been clearly proved to be not the segment of a sphere, but of an ellipsoid, with three unequal axes, the long (antero-posterior) axis corresponding to the axis of the globe; whilst the other two axes are—one, the longer, as a rule, horizontally, the other, the shorter axis, vertically disposed. The consequence of this is that (with one fixed accommodation) vertical and horizontal rays of light have two different foci. To see a vertical line distinctly, all the horizontal rays emanating from it must be accurately focussed on the retina. The vertical rays have no such necessity, for the circles of diffusion resulting from imperfect focussing overlap one another, so as not to interfere with the definition of the line, excepting at its upper and lower ends. *Mutatis mutandis*, the same facts hold good as regards the accurate perception of horizontal lines. If we now, on a piece of cardboard, draw a set of vertical and a similar set of horizontal lines, accurate observation shows that very few eyes are able to perceive both sets at the same time with the same degree of distinctness. This proves that few, if any, eyes possess the same focus for horizontal and vertical pencils of light. This inequality of refractive power of the different meridians of the eyeball was named by Professor Whewell "Astigmatism" (from *a*, privative, and *στίγμα*, point=focus). Astigmatism is, then, a normal state of the human eyeball; but it exceptionally amounts to so substantial an optical defect as to require treatment, and in this sense only we shall hereafter employ the term in question. Up to the time of Donders's recent researches, only eleven cases of astigmatism had been recorded during a period of nearly seventy years. Thomas Young, in 1793,* was the first to discover this defect in his own eye. This, "in a state of relaxation, collects to a focus on the retina those rays which diverge vertically from an object at the distance of ten inches from the cornea; and the rays which diverge horizontally from an object at seven inches distance."† Consequently, the refraction of his globe was greater in the horizontal than in the vertical meridian. In 1827, Professor Airy published a remarkable instance of the same anomaly in his own (left) eye.‡ It will be readily understood that astigmatism may ensue from other causes than those of an inequality of curvature of the meridians of the cornea. The same inequality in the curvature of the surfaces of the lens, any abnormal position (or dislocation) of this latter will produce astigmatism. Many persons who wear glasses are doubtlessly constantly astigmatic from the slanting positions the lenses of these glasses acquire from imperfect adaptation of the frames, or from their bending, by the habit many persons have of carrying their spectacles carelessly in their pockets without the case. Astigmatism may be recognized by the following signs:—

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* If we call a line passing through the yellow spot and the centre of the eyeball the optic axis; one passing through the centre of the cornea, and the centre of the eyeball the globe's axis; then in emmetropic eyes the optic axis cuts the globe's axis to the inner side of the cornea's centre at about an average angle of 5°, in myopic eyes of 2°, in hypermetropic eyes of 7°.

1. A defect in visual power of an optical nature not remediable by ordinary spherical lenses. A patient presents himself with defective vision. With or without ordinary glasses, as the case may be, he finds it impossible to read, say No. 19 of Jäger, at twenty feet. This may be due to some organic or functional disease of the tissues of the globe; or it may be

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* Philosophical Transactions, vol. lxxxiii. p. 169.

† Philosophical Transactions, for 1801.

‡ Transactions of the Cambridge Philosophical Society, for 1827, vol. ii. p. 267.

due to astigmatism. To which of these two categories it belongs becomes, then, a matter for further investigation.

2. For simplicity, we may regard the rays of light emitted from a luminous point as consisting of two sets—vertical and horizontal rays. If an astigmatic eye unites either of these two sets accurately to a focus point on the retina, the other set forms a linear image (produced by a series of circles of diffusion linearly disposed) on the retina. Thus an astigmatic patient, instead of perceiving a luminous point as a point, perceives it as a line, vertically or horizontally disposed, according as, by his accommodation, he is focussing the horizontal or vertical rays respectively. But the refraction of the eye in question may be such as to prevent the patient's bringing either of these two sets accurately to a focus. In such a case, where the circles of diffusion are exactly of the same size, the luminous point will appear as a circle of diffused light: in all other positions between the two linear images as an ellipse with its major axis, vertical or horizontal, according as the circles of diffusion arising from the vertical or horizontal rays are the larger in area. But, as will readily appear from a little reflection, we can always find a lens, either convex or concave, which will unite the less or more refracted of the two sets of rays. The direction of the line observed by aid of the convex lens represents that of the meridian of maximum curvature (refraction) of the cornea, and *vice versâ* with the concave lens. The distance between the two linear images is the "focal interval" of Sturm, and varies proportionately to the astigmatism present. All these facts may be beautifully illustrated by observing the forms of the images thrown on a screen from a distant luminous point by a refractive combination, say, of a 6-inch ordinary spherical convex lens, next to which is placed, say, a 30-inch convex cylindrical lens,* with its axis, say, vertical. When the screen is five inches from

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* I find the most convenient source of obtaining a luminous point is from a magic lantern, the light from which is allowed to pass through a perforated blackened diaphragm. The cylindrical lens in question (as will be hereafter fully explained) refracts all the horizontal rays of the luminous point to a focus at 30 inches, whilst all the vertical ones undergo no refraction whatever, but pass through perfectly unchanged in their direction. The screen in our experiment represents the retina.

this compound lens, the horizontal rays will be accurately united to a focus, having been refracted (1) by the 6-inch spherical, and (2) by the 30-inch cylindrical lens $(\frac{1}{6}+\frac{1}{30}=\frac{1}{5})$. The vertical rays, on the other hand, are in progress of union to a focus, but are not yet united, and will, consequently by their circles of diffusion, produce a vertical line on the screen. When, on the other hand, the screen is six inches from the compound lens, the vertical rays are united to a point, whilst the horizontal ones, having been already united at five inches, as above, have diverged again, and form a horizontal line on the screen. In an intermediate position, between five and six inches, the image is that of a circle, whilst in front of this circle it is an ellipse, with its major axis vertical; behind it, one with its major axis horizontal. If we suppose the screen to be fixed, as the retina is, say in some position intermediate between either of the positions necessary to exhibit either of the two linear images, a little reflection will show that, by means of an appropriate convex or concave lens, we may throw forwards or backwards the entire system of images in such a way as to successively bring the horizontal or vertical linear images on to the screen. Or we may suppose the screen fixed altogether in front or altogether behind the limits of the two lines (the focal interval). In the first case (one of inequality of hypermetropia in the two meridians), an appropriate convex lens will evoke a vertical line, a still stronger one a horizontal line on the screen, and *vice versâ* in the second case (one of inequality of myopia in the two meridians); and these experiments are most instructive, and agree very accurately with what is observed in most cases of marked astigmatism.

A consideration of the above facts will explain all the various appearances a luminous point may assume to an astigmatic eye, with or without the aid of an auxiliary lens. In all these experiments it is absolutely necessary that the patient should hold the head perfectly vertically, as the directions of the linear images vary according to the inclination of the head.

3. The inability to perceive vertical and horizontal lines at the same time with equal distinctness. The *rationale* of this has been before considered, and is a mere case of linear

aggregation of luminous points. As from (2) may be inferred, the indistinct set may be rendered distinct by an appropriate spherical lens, when the set previously distinct becomes indistinct.

4. We may destroy the astigmatism by letting the patient see through a narrow slit (about two millimetres broad); this permits only the vertical or horizontal rays of objects to strike the cornea accordingly as it is held vertically or horizontally. By far the most practical way is to test the far-point in each meridian by a small type, with an auxiliary convex lens, by the method detailed at p. 47. I am indebted to Mr. Windsor for this practical hint. We may thus investigate the refraction of each meridian separately: this may be normal, myopic, or hypermetropic (the latter two may be of different degrees), so that we may (theoretically) have eight different varieties of refraction of the cornea. The most common case is for the cornea to have its maximum refraction in the vertical meridian, as in Airy's case, but it may be in the horizontal meridian, as in Young's, whose case is further exceptional in the astigmatism having been due to some irregularity of the lens, whereas it is in by far the vast majority of cases due to some irregularity of curvature of the cornea.

5. Astigmatism may be remedied by cylindrical lenses, always presupposing that any general optical defect of the eye has been previously corrected by its proper spherical lens.

A spherical lens is a segment of a sphere, and refracts the incident rays of light equally in all planes of the segment; a cylindrical lens is the segment of a cylinder, and refracts rays of light most in a plane at right angles to the axis of the cylinder, of which it is a segment, whilst those rays of light which strike it in the plane of the axis, undergo no refraction whatever. For the sake of simplicity we may therefore restrict our considerations to these two directions—that of the axis and that of the transverse diameter. A 6-inch convex cylindrical lens means one which refracts a pencil of parallel rays, thus: (1) those which strike it parallel to the transverse diameter of the cylinder are focussed at 6 inches from the surface of the lens (2), those which strike it parallel to the axis of the cylinder are not focussed at all by the lens, but pass through it refracted not more than they would have been by passing through a piece of plane glass. Of a pencil of parallel rays striking a 6-inch concave cylindrical lens: (1), those which impinge in the plane of the transverse diameter acquire thereby a divergence as if they had proceeded from a point 6 inches from the surface of the lens, whilst (2) those which impinge in the plane of the axis retain the same direction they had before impaction. It is thus apparent that we in cylindrical lenses have (as was first pointed out by Airy) the means of correcting the refraction of one meridian of the eye, leaving the other in its original state—of correcting the astigmatism.*

The following cases are illustrative of the facts and principles above laid down :—

CASE VII.—*Myopic Astigmatism* ($\frac{1}{20}$) *due to Unduly High Curvature of the Vertical Meridian, remedied by a Cylindrical Lens.*

Mr. A., æt. 24, consulted me for acute asthenopic symptoms, which had become more especially severe during the time he had been reading hard for a University degree. He had for many years worn concave glasses, which he had found it necessary to change several times for ones successively stronger, till he at last used ones of 5 inches focal length. There was no marked insufficiency of the internal recti muscles. Before examining his eyes with the ophthalmoscope, I expected to find extensive staphylomata postica, if not more serious organic lesions, of the fundus oculi. But to my surprise the appearances were altogether at variance with the apparently high degree of myopia present. In truth there were hardly any appreciable deviations from the natural state of the fundus, nor was the indirect image definable without the use of an object lens.

This led me to suspect the presence of astigmatism.

Left eye.—(1) With a 6-inch concave at 8 feet vertical lines appear very indistinct, horizontal ones distinct, and *vice versâ* with a 14-inch concave.

(2) With a 4-inch concave at 8 feet a luminous point appears as a narrow *horizontal* line, thickened at its centre with a 12-inch concave as a narrow *vertical* line.

(3) Further investigation showed that the eye was myopic in the horizontal meridian to a $\frac{2}{20}$, in the vertical to a $\frac{3}{20}$.†

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* A complete set of cylindrical trial-lenses may be procured of Murray & Heath, 143, Piccadilly.

† The numerical discrepancies in observations (1), (2), and (3) are probably due to variations in the patient's involuntary accommodation.

With a combination of a 10-inch spherical concave and a 20-inch cylindrical concave (axis horizontal) the appearances (1) and (2) disappeared, and his *visual power was exactly double* of that with his old glasses on (from $S=\frac{1}{4}$ to $S=\frac{1}{2}$). For at 8 feet with a 5-inch concave on he only read XXX ; with the above combination he read XV.

The right eye was also astigmatic, though not to quite so high a degree as the left.

This case is interesting from its singular completeness, illustrating, as it does, nearly all the preceding observations in a truly practical manner.

Case VIII.—*Myopic Astigmatism* ($\frac{1}{20}$) *Limited to the Right Eye.—Oblique Position of the Axes of Curvature.—Application of a Cylindrical Lens.*

Wm. M., a painter, applied at the Ophthalmic Hospital, Southwark, in September, 1863, on account of his sight gradually failing him, especially in his right eye. He had never had any symptoms of lead-poisoning, excepting slight wrist-drop. Notwithstanding this his failure of sight had been attributed, by a well-known ophthalmic surgeon, to lead.

On testing his vision I found that with a 11-inch concave to the right eye he read No. 23 at 20 feet ; with the left eye No. 20 ; but with a 24-inch concave No. 18 at the same distance.

The opththalmoscope disclosed evidence of subacute retinitis in both fundi, and a singularly distinct and extensive pulsation of the retinal veins in both eyes.*

After treatment of the retinitis, his vision improved in either eye; but still that of the right eye remained almost as defective as before, till at last we began to suspect the presence of astigmatism, which was completely established by the following observed facts :—

Right eye.—At 8 feet with a 9-inch concave sees vertical lines somewhat plainer than horizontal ones ; with a 12-inch concave the reverse. With a 12-inch concave a luminous point assumes the appearance of a point with two linear expansions directed upwards and inwards, at an angle of about 20° from the vertical. With a 12-inch concave spherical, plus a 20-inch concave cylindrical lens, its axis inclined as above, he is enabled to read No. 19 at 20 feet, although with either glass alone he cannot read No. 23 with any degree of certainty.

If he with a 9-inch concave regards a series of lines inclined at about 20° to the vertical, and a second set at right angles to these latter, both set appear equally distinct to him. An oblique position of his head, or of the concave glass, produces the same effect.

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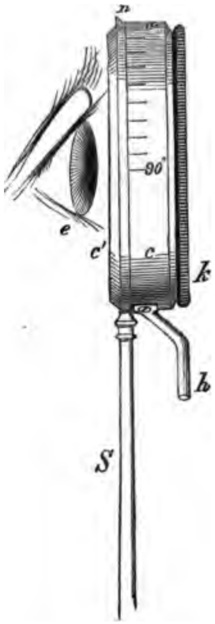
* Since my attention has been drawn to this fact, I have found pulsation of the retinal veins a by no means uncommon incident to the normal fundus oculi.

The inference to be drawn from the above facts is that in the right eye there is a general myopia of $\frac{1}{13}$, with a second superadded myopia of $\frac{1}{30}$ (constituting the astigmatism), in the upward and inward meridian of the globe.

October 24 (dull day).—*Oc. d.* with his cylindrical concave now only reads 22—both papillæ opticæ red, staphyloma post. (inwards) in left eye, less in right eye ; pulsation of veins still seen.

In several other cases of astigmatism, which I have investigated, I have found that the principal axes of curvature deviated more or less from the vertical and horizontal directions. I have also observed that astigmatic patients are remarkably sensitive to the slightest deviation of the axis of the cylindrical glass from that which most completely corrects the asymmetry, the least change of position of the axis at once lowering the acuteness of vision. It is therefore not only scientifically, but practically necessary to be able to determine and note for the guidance of the optician the precise angular position of these axes.

Fig. 27.



The instrument [Astigmometer] (Fig. 27) for this purpose consists essentially of a circular shallow white-metal cell (*c*), into which the cylindrical glass is adapted by a collar (*k*). The cell is graduated in half its circumference into degrees, commencing at 0,° and extending on each side from 0° through all intermediate degrees to 90°. The cell is revolvable by a handle (*h*) at the opposite point of the circle to 0°, around a fixed second brass circle (*c′*); this latter is fixed to the stem (*S*) of the instrument, so that it can be held by the hand of the surgeon in front of the patient's eye (*e*). The circle (*c′*) has a notch (*n*) corresponding to its uppermost point when the instrument is held vertically. In using the instrument, the cell (*c*) is first brought by the handle (*h*) into such a position that 0° corresponds exactly to the notch (*n*); the cylindrical glass is now dropped into the cell (*c*), so that the axis of the lens corresponds to *n* and 0°, and is fixed in this position by the collar (*k*) which, to avoid any angular displacement of the lens, slides—not screws—into *c*. The instrument being now held vertically before the patient's eye in the same plane as the cornea, the handle (*h*) is turned round till the greatest definition of vision is obtained. The inclination of the axis of the lens is now read off by seeing to which of the degrees on *c*, *n* corresponds.

CASE IX.—*Myopic Astigmatism* ($\frac{1}{16}$) *in the Vertical Meridian, remedied by Cylindrical Lenses.*

Hannah M., aged 24, a tailoress, consulted me at the Ophthalmic Hospital, Southwark, in September, 1861, on account of asthenopia, from which she had suffered for the last ten years. The symptoms were dimness of vision, a sensation of " burning " in the eye-balls, congestion, and lachrymation, all of which came on after reading, &c., for a quarter of an hour, or after five minutes, if she had previously been hard at work at her business. I found that No. 22 was the highest type she could read at 15 feet distance ; and finding that no glasses, either convex or concave, enabled her to read any lower type, I, after a month's ineffectual treatment by tonics, eye-waters, rest, &c., gave her case up in despair.

On the 13th of February, 1862, I desired her to call on me, with a view of seeing whether, perhaps, her symptoms depended on astigmatism.

Repeated examinations yielded the following results with each eye :—

1. On requesting her to regard a luminous point of two millimetres' diameter, and placing a 20-inch convex lens before the eye, she, after a time,* declared it appeared to her as a narrow vertical line.

2. On her regarding a series of black, vertical, and horizontal lines at about 8 feet off, she saw the vertical ones perfectly distinctly, the horizontal ones very indistinctly ; a 16-inch spherical concave glass reversed the order of things—the horizontal lines then became distinct, the vertical ones indistinct.

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* In experimenting on my own eyes with cylindrical lenses, I have observed the phenomena of astigmatism of a luminous point never appeared perfect, till a sufficient time was allowed for my accommodation to settle down into one constant condition.

3. With the naked eye, at 12 feet, she could read no lower than XX of Snellen's Types; but with a cylindrical concave lens of 16 inches' focus, she read XII. Thus, her "sharpness of definition" increased from $\frac{12}{20}$ ($=\frac{2}{3}$ nearly) to 1—became, in fact, absolutely perfect. This only occurred, however, when the axis of the cylindrical lens was transversely placed: if vertically, she could hardly see at all. In order to eliminate all source of error, I tried the crucial experiment of placing an ordinary (spherical) 16-inch concave glass before the eye: this only made her see worse than with the naked eye.

I then found that she, with her cylindrical glasses, could also read an ordinary printed book at a usual reading distance without feeling any fatigue in the eyes.

Both eyes, on careful examination, proved to be equally astigmatic.

From the above it follows that this patient's eyes possess a normal refraction in their horizontal meridians, but are myopic ($\frac{1}{16}$) in the vertical ones, her astigmatism equalling $\frac{1}{16}$.

Case X.—*Hypermetropic Astigmatism* ($\frac{1}{18}$) *of Left Eye.*

Mary D., æt. 49, consulted me, on November 15th, 1862, on account of asthenopic symptoms. After repeated examinations, I found that she was emmetropic in the right eye, but that in the left eye there existed an hypermetropia of $\frac{1}{18}$ limited to its horizontal meridian, as evidenced by the following facts:—

1. Horizontal lines at 8 feet appear to her more distinct than vertical ones, and *vice versâ* with an 18-inch convex. An 18-inch convex, cylindrical, axis vertical, makes both set appear equally distinct.

2. With an 18-inch convex a luminous point assumes an oval shape, the axis being slightly out of the vertical.

3. With an 18-inch convex, cylindrical, axis vertical, her visual power (*vide* Case VIII.) is doubled. She is also presbyopic with either eye to about a $\frac{1}{16}$.

With glasses corresponding to the above facts she reads No. 2 at 11 inches, without any asthenopic symptoms.

Case XI.—*Hypermetropic Astigmatism.*

In May, 1863, I received a letter from a British physician in practice in South America, giving a very lucid description of his case, which I transcribe, as far as possible, in his own words:—

He is 30 years old, and had suffered from childhood from weak sight, and had never been able to read by artificial light anything but the largest print; but up to within the last four years could read the *Times*, including advertisements, without glasses. Being obliged to write at night, he began to use slightly convex glasses, which enabled him to see more clearly, but always magnified objects. Finding his sight became weaker, even by day, he gradually continued the use of glasses by day, and now cannot read even a leading article in the *Times* without them, and for not longer than twenty minutes at a time. On repeating the experiments of astigmatism, he obtained the following results :—

1. A luminous point was converted into a vertical line by an 8-inch convex lens.

2. At 5 yards he saw horizontal lines plainly, vertical ones not at all, merely a grey colour in their place. With a 6-inch convex lens, the definition of the lines was reversed.

He further on says :—" I had long known this peculiarity of my sight. . . After half-an-hour's reading I am unable to distinguish *m* from *n*, or the Roman number III. from II. ; and looking at our town clock from a distance, I can see the hands when they point to IX. or III., but not when they are directed towards XII. or VI. . . . . All kinds of stuffs, cloth, &c., when striped vertically with black appear to me grey, unless the lines are far asunder, and then they dazzle me." He then very correctly diagnoses his case thus :—" From these observations I have concluded my refraction is natural in the vertical plane, but presbyopic (*should be 'hypermetropic'*) in the horizontal."

CASE XII.—*Compound Hypermetropic Astigmatism Limited to Left Eye.—Hypermetropia of Vertical Meridian*$=\frac{1}{14}$, *of Horizontal*$=\frac{1}{7}$. Vide similar case in Donders' Tract, p. 109.

James B., æt. 13, asthenopic for three years.

1. RIGHT EYE.—Normal ; reads 19 (Jäger) at 20 feet ; glasses produce no effect.

2. LEFT EYE.—Reads no type at 20 feet ; with 16 convex 23, and at 3 feet horizontal lines much clearer than vertical ones.

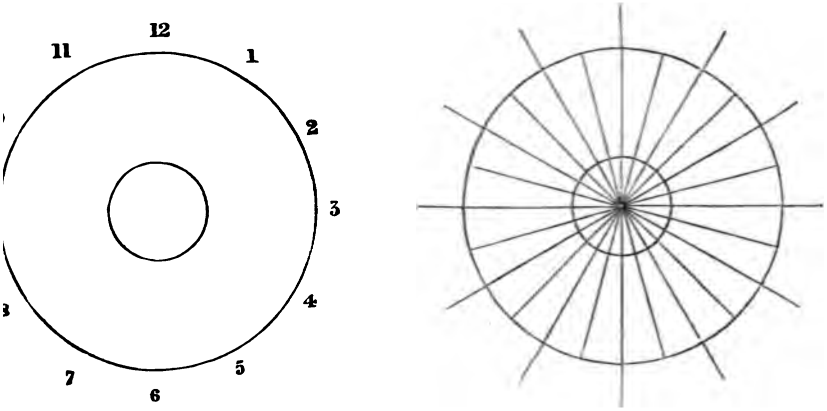
Results after Paralysis of Accommodation by Atropine (*gr. iv. ad.* ℥*j*).—Reads at 20 feet no type, with 14 convex 23. Appearances of a luminous point at a few feet : with 8 convex as a line pointing upwards and inwards ↖ ; with 14 convex as a line pointing upwards and outwards ↗ ; with 14 convex spherical and 14 convex cylindrical (axis upwards and inwards) the point appears round. With this last combination at a few feet horizontal and vertical lines appear equally distinctly, and 22 is read well at 20 feet. With the ophthalmoscope the direct image is seen well without an eye-piece ; the outer edge of the optic entrance is ragged and ill-defined, with a few granular pigment spots.

In this case I have reason to believe that a *third* meridian of astigmatism exists, but up to going to press I have not yet had time to investigate it.

Whilst these sheets were going through the press, my attention was attracted to a very interesting paper on astigmatism, by Javal (*Annales d'Oculistique*, for January and February, 1865). The following extract contains a new method of determining the existence and amount of astigmatism:—

"1. *Monocular Demonstration.*—Draw a circle with radii 15° from each other, and let the patient view this figure through a lens, which, for the sake of precision, I will suppose to be a 3-inch one. Withdraw the figure gradually, till all the lines become dim, or disappear, excepting one. Then try all your cylindrical concaves, one after the other, beginning with the lowest powers, with their axes perpendicular to the radius, which has remained black, till you have found the glass which makes all the radii equally black. You have then at once diagnosed astigmatism and determined the number and position of the correcting glass. . . . For every person with binocular vision the following procedure is much more preferable.

FIG. 28.



"2. *Binocular Determination.* — We now add before the other eye a lens and a circle, identical with the preceding ones, the circle being first at the focal lengths of the glasses with their centres as far apart as the distance between the two eyes. The circles cannot be fixed, excepting the visual lines are parallel and the head straight. The relative position of the visual lines being a fixed one, this sufficiently guards against any changes of accommodation.

That the patient may readily say what he sees, the radii are marked with the same numbers as the hours of a watch, and these numbers not being seen by the same eye as the radii, afford a constant test of binocular vision.

"M. Nachet has constructed an apparatus realizing the above conditions. By a simple mechanism the circles may be moved forwards or backwards, or the lenses may be decentrated, so as to always face the two images, and in less than a minute the whole series of cylindrical glasses may be submitted to the eye in any desired position............"

CHAPTER VII.

PRESBYOPIA.

THE normal eye of a young subject can generally accommodate to as close a distance as four inches, and even closer. But, as every one knows, persons in advanced years are, if they do not use glasses, obliged to read, work, &c., at a considerable distance from the eye. In other words, their near-point has receded. If you were to be guided solely by the etymology of the word presbyopia, you might be led to believe this recession of the near-point only occurred in old persons; but the fact is, that it commences in early life (according to Donders, from the tenth year of age), progressively increases, but does not come to be felt as a substantial annoyance till after about the fortieth year. For practical purposes it is best to take presbyopia in this limited sense. When shall we, then, say presbyopia commences? Donders says, when the near-point has receded beyond eight inches from the eye: I think about ten inches would be a more practical standard. However, the chief circumstance I wish you to observe is that the definition is a purely artificial one, founded on the conventional exigencies of life. Indeed, presbyopia might be said to vary with the pursuits of a person; for, accordingly as these demand a greater or less closeness of vision, will he, or will he not, feel any inconvenience from his defective accommodation. In this sense, for example, a tailor or a student becomes presbyopic at an earlier age than a seaman or a soldier.

The estimation of the *amount* of presbyopia in any given case will now claim our attentive consideration, as it affects the three classes of eyes.

1. *Presbyopia in Normal Eyes.*—Let a person be able to

see with his naked eyes distant objects, but not near ones distinctly any closer than, say, fourteen inches, what amount of accommodation does he possess? — Answer: $\frac{1}{14}$ (*vide suprà*).

There is one objection that may be urged against this method of estimation, viz., that the convergence of the eyes for fourteen inches is too low to elicit all the energy of accommodation the patient is actually endowed with. We may, however, control our observations by putting the patient on a pair of strong convex glasses—say a 10-inch pair—and then seeing how much nearer he can accommodate than ten inches from the glasses. This was the plan adopted by Macgillavry;* as the learned author of an elaborate article in the 57th vol. of the *British and Foreign Medico-Chirurgical Review* very justly observes,—"It is advisable not to use too strong glasses, for, owing to the increased size of the image, the circles of dissipation are not so soon perceived."

According to our assumed standard near-point of eight inches for the commencement of presbyopia, the minimum amount of accommodation a person must possess *not* to be presbyopic is $\frac{1}{8}$; but in our supposed case he has only $\frac{1}{14}$. Therefore the *difference* between these two fractions: $\frac{1}{8}-\frac{1}{14}=\frac{1}{19}$ (nearly)—expresses the deficit of accommodation—the presbyopia—the patient labours under. For distinct vision at eight inches he finds himself *minus* such an amount of accommodation as is equivalent to a 19-inch convex glass lens.† If we, therefore, artificially supply him with such a lens, we at once correct his presbyopia, always with the proviso that, if he himself at the same time employs *all* his natural accommodation ($\frac{1}{14}$), he will then be able to read, work, &c., at eight inches. Few persons, however, would be able to endure such a strain on the ciliary muscle for any length of time without fatigue (asthenopia); but, on the other hand, few persons desire to employ their eyes continuously for so close a distance as eight inches. For such convenient distances as 10, 11, or 12 inches, convex glasses of 19 inches focus will answer admirably without overtaxing the patient's natural power of accommodation. Thus, *e.g.*, for reading at 12 inches he will only have to use $\frac{1}{32}$ accommodation, which is about half of the entire amount he has ($\frac{1}{32}:\frac{1}{14}=\frac{1}{2}:1$, nearly). At 19 inches off, with his presbyopic glasses of $\frac{1}{19}$ on, he will, of course, have to entirely suppress his accommodation. Beyond that distance he will not be able to see at all (nor will he require to do so) with his presbyopic glasses on.* If $\frac{1}{A}$=the presbyopic's natural accommodation, the glass he requires is then given by the formula, $\frac{1}{8}-\frac{1}{A}=\frac{1}{f}$, where f=the focal length of the required glass. This result of theory must, however, always be checked by actual clinical observation. As a rule, on account of the convergence of the optic axes, the patient generally prefers a lower glass than the one given by the above formula. I may say, generally, that in prescribing a pair of glasses for a presbyopic, your object should be to reinforce his defective accommodation by convex lenses, neither so strong as to supersede his own remaining natural accommodation, nor so weak as to tax it further than it admits of. The following table from Dr. Kitchener's "Economy of the Eyes" may give a general idea of the glasses required at different periods of life :—

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* Onderzoekingen over de Hoegrootheid der Accommodatie. Utrecht, 1858.

† Convex glasses in presbyopia act in two ways: (1) they increase the divergence of rays, (2) they magnify. We always find patients can read a larger type with them.

Years of age.	Inches of focus.	Years of age.	Inches of focus.
40	36	70	12
45	30	75	10
50	24	80	9
55	20	85	8
58	18	90	7
60	16	100	6
65	14		

Donders gives a similar table of what glasses are required at different ages in emmetropia, with normal acuteness of vision and accommodation, for writing, and for reading ordinary type.

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* I have, at the risk of being prolix, adduced these various illustrations of presbyopia in order that the reader, by perceiving their several truths, may satisfy himself that he has thoroughly understood the points at issue.

a Age.	Glasses required. *b* In present *E*.	 *c* In original *E*.	*d* Distance of distinct vision.	*e* R_2.	 P_2.
48	$\frac{1}{60}$	$\frac{1}{60}$	14″	60″	10″
50	$\frac{1}{40}$	$\frac{1}{40}$	14″	40″	12″
55	$\frac{1}{30}$	$\frac{1}{28}$	14″	30″	12″
58	$\frac{1}{22}$	$\frac{1}{20}$	13″	22″	12″
60	$\frac{1}{18}$	$\frac{1}{16}$	13″	18″	12″
62	$\frac{1}{14}$	$\frac{1}{12}$	13″	14″	12″
65	$\frac{1}{13}$	$\frac{1}{10}$	12″	13″	11″
70	$\frac{1}{10}$	$\frac{1}{7 \cdot 5}$	10″	10″	10″
75	$\frac{1}{9}$	$\frac{1}{6 \cdot 5}$	9″	9″	9″
78	$\frac{1}{8}$	$\frac{1}{5 \cdot 5}$	8″	8″	8″
80	$\frac{1}{7}$	$\frac{1}{4 \cdot 5}$	7″	7″	7″

"Column *b* gives the glasses required for *E* (*Emmetropia*), proved at the moment; *c* for *E* in youth, and therefore for *H* (*Hypermetropia*), acquisita at the time of observation; in both cases the diminished acuteness of vision belonging to the time of life is taken into account; *d* indicates the distance which is preferred for vision with these glasses; *e*, finally, the space through which they admit of acute vision, that is from R_2 with the least, to P_2 with the greatest convergence $\left(\frac{1}{A_2}=\frac{1}{P_2}-\frac{1}{R_2}\right)$."—Donders' work on Accommodation and Refraction, p. 220, 1.

2. *Presbyopia in Myopic Eyes.**—You will in practice find that all the higher myopic eyes, as a rule, are more or less deficient in accommodation—more or less presbyopic, we might almost say. But presuming we adopt our previous standard of

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* Mr. White Cooper quotes several cases of the kind at p. 101 *et seq.* of his treatise "On Near Sight, Aged Sight, &c."—a work which, although not up to the knowledge of the present day, may still be advantageously consulted on many practical details in the management of cases of defective vision.

presbyopia, it is clear that the term is inapplicable to all degrees of myopia above $\frac{1}{8}$; for their far-point is already less than 8 inches, and *à fortiori* their near-point. But when we come to deal with low degrees of myopia you will find, at a certain age, presbyopia a very usual concomitant. For example, a person's eye presented this combination—(1) the far-point was 20 inches; (2) the near-point 12 inches. On account of (1) the patient is myopic; of (2) he is also presbyopic. He is short-sighted and long-sighted at the same time. His far-point is too close; his near point too far. In fact, his range of distinct vision with the unaided eye is comprised in a line of 8 inches. His power of accommodation, $\frac{1}{A}$ is $\frac{1}{12}-\frac{1}{20}=\frac{1}{30}$.* What glass would the eye require (abstracting ourselves for a moment from the co-existing myopia), using its entire $\frac{1}{30}$ of accommodation to read distinctly at 8 inches?

$$\frac{1}{8}-\frac{1}{30}=\frac{1}{10\frac{10}{11}} \text{ nearly:}$$

a convex glass of 11 inches focal length, therefore, corrects the presbyopia, but we must also correct the myopia (of a $\frac{1}{20}$). In other words, from $\frac{1}{10\frac{10}{11}}$ we must subtract $\frac{1}{20}$ which gives $\frac{1}{24}$ nearly.† A convex glass of 24-inches focus is the glass required to correct simultaneously the presbyopia and the myopia. Generally, if $\frac{1}{A}=$ the patient's accommodation, $\frac{1}{M}$ his myopia, the glass required to neutralize his presbyopia and myopia together is given by the formula $\frac{1}{8}-(\frac{1}{A}+\frac{1}{M})=\frac{1}{F}$, F being the focal length in inches of the required convex glass. This patient required a 20-inch concave for distance, a 24-inch convex for near objects. If $\frac{1}{A}+\frac{1}{M}$ is greater than $\frac{1}{8}$, $\frac{1}{F}$ is negative. In other words, the resulting fraction expresses the power of the *concave* glass the patient will require for near objects. This, of course, will always be a lower power than the one he uses for distance.

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* The rationale of this formula is as follows:—If the eye were a normal one $\frac{1}{A}$ would $=\frac{1}{12}$. But we know the eye's refractive power is too great by a quantity=a $\frac{1}{20}$ (convex glass lens). Thus part of the $\frac{1}{12}$ is really due to this $\frac{1}{20}$. We must, therefore, *subtract* this $\frac{1}{20}$ from the $\frac{1}{12}$, in order to estimate the amount of *active* accommodation the patient *bonâ fide* possesses—indeed, the myopic condition of such an eye is by some authors considered to be the result of a certain portion of the patient's accommodation having become, so to say, *fixed* by partial spasm of the ciliary muscle. Correct the myopia ($\frac{1}{20}$) by a 20-inch concave glass, and the near-point is no longer at 12 inches, but at 30 inches.

† We may carry this out in practice by ascertaining the near-point of the patient with his reducing concaves on. This, in the above case, is 30 inches. From $\frac{1}{8}$ subtract $\frac{1}{30}$, and from the result $\frac{1}{20}$, and the final result will be $\frac{1}{24}$, as before.

To take an example. Let $\frac{1}{A}$ in a given case $=\frac{1}{11}$, and $\frac{1}{M}=\frac{1}{14}$, then $\frac{1}{8}-(\frac{1}{A}+\frac{1}{M})=\frac{1}{8}-(\frac{1}{11}+\frac{1}{14})=\frac{1}{8}-\frac{1}{6}=-\frac{1}{24}$. This patient requires a 14-inch concave for distant objects, a 24-inch concave for near ones.

These results of calculation applied to practice will be mostly found correct, but must, notwithstanding, always be checked by clinical experience of the case itself.

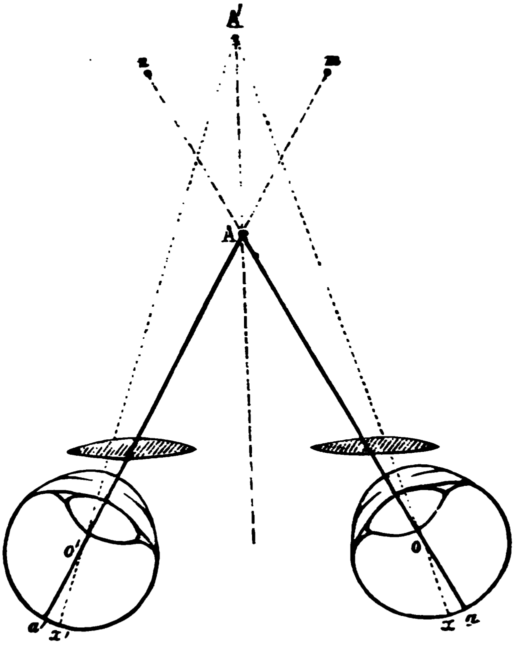
(3) *Presbyopia in Hypermetropic Eyes.*—A little reflection will show that in this combination the amount of latent hypermetropia is too small to require being taken into account. Having ascertained the amount of the manifest hypermetropia present, we may, of course, from the position of the near point, readily estimate that of the presbyopia. For example, a person has a hypermetropia of $\frac{1}{10}$, but with his 10-inch convex glasses cannot see nearer than 24 inches. To see at 8 inches he will require glasses of $\frac{1}{10}+\frac{1}{8}-\frac{1}{24}=\frac{1}{5\frac{1}{2}}$ nearly; with 5½-inch convex glasses to read at 8 inches he will have to use all of his natural accommodation ($\frac{1}{24}$), but does not for any distances further than 8 inches.

What is the proximate cause of presbyopia? It may be due to deficient power of the ciliary muscle or to increased hardness of the lens. It can hardly be called a disease any more than grey hairs or atrophy of the lower jaw. Donders and myself have observed that with advancing age persons may grow not only presbyopic, but at last actually hypermetropic (probably from loss of tonicity of the ciliary muscle), so as to require convex glasses even for distance. Porterfield (vol. ii. p. 69) observed the same, "that long-sighted people at last cannot see at all without the assistance of spectacles."

EFFECT OF BINOCULAR VISION ON THE USE OF GLASSES.

In all that has preceded we have regarded each eye separately without taking cognizance of any modifications the application of glasses might require to fulfil any additional circumstances attending the exercise of the two eyes together—*binocular* vision. This subject has been specially, and deeply, studied by my valued friend Dr. Giraud-Teulon, of Paris, of whose views I now proceed to give a short abstract.

Fig. 29.



Supposing the two presbyopic eyes (in Fig. 29) at their maximum accommodation to have the near-point A′, and that the two convex lenses produce virtual images of the point A at the same distance as that of the near-point, then the eye *o* will perceive an image of *A* at *n*, the eye *o′* one at *m*; there will, in a word, be crossed diplopia; this is, however, overcome by the eyeballs converging to *A*, by which means the two images, *m* and *n*, are fused at the point *A′*. The eyes are then converged to A, but accommodated for A'. Hence the natural harmony of convergence and accommodation is broken. By using, however, only the external portions of the two lenses, the two images, m and n, may be fused without any such unnatural convergence of the globes, a physical (prismatic) action being substituted for a physiological. It is evident that to use the internal halves of the lenses would only be constraining a still higher degree of convergence on the eyeballs. Such are the theoretical considerations advanced by Dr. Giraud-Teulon. These he experimentally endeavours to corroborate by the fact that, if we cover the external halves of the lenses of a pair of convex glasses and then regard a near object, crossed double vision is at first produced, and by certain arguments derived from stereoscopic considerations. He hence advises the use of eccentric lenses (*lentilles décentrées*) in the manufacture of spectacles, by which, he states, no muscular effort being required, vision is rendered materially easier and less fatiguing.

The same considerations reversed apply to the use of concave glasses for myopic patients; in them the thinner halves of the glasses being mounted inwards, whilst in presbyopic ones they are outwards. For the details of the theory and application of these decentrated lenses, I must refer to Dr. Giraud-Teulon's own work on binocular vision, p. 394, *et seq*. Of the validity of the reasons there adduced for the use of decentrated lenses, I am not yet in a position to offer any definite opinion, as the entire problem still requires an extended clinical experience for its ultimate solution.

CHAPTER VIII.

PARALYSIS OF ACCOMMODATION.*

THE prominent diagnostic sign of Paralysis of Accommodation is an impairment of vision for near objects, whilst that for distant ones remains, in the majority of cases, comparatively unaffected. This second clause refers, however, only to loss of accommodation as it occurs in the normal (emmetropic) eye; for, should the refraction of the affected eye have originally been defective in converging power (hypermetropic) in its conformation, with a tolerable range of accommodation, then its vision will commonly be found to be diminished, not only as regards near objects, but also for distant ones. This latter defect will therefore require to be corrected by suitable convex glasses, before we proceed to examine into the amount of accommodation available for near objects.

I have not yet seen paralysis of accommodation occurring in a myopic patient, but I should imagine that in such a case vision would remain unimpaired for distance, whilst the near-point would be removed further off from the eye.

Presuming that the eye (if necessary) has been in the first instance restored to a state of normal refraction by suitable glasses, the near-point will be found (taking into consideration the age of the patient)† to be abnormally distant from the vertex of the cornea, but may be approximated as closely as we please by the appropriate convex glasses (*Vide* Cases XIV., XV., and XVI.).

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* This chapter is a reprint from a paper Mr. Robt. C. Moon, House Surgeon to the Ophthalmic Hospital, Southwark, drew up under my supervision, and published in the first number of the *Ophthalmic Review.* In it the effect of the Calabar bean in such cases is especially referred to.

† For the average diminution in range of accommodation in emmetropic eyes at different ages, see the table given by Professor Donders in "Ametropie en hare Gevolgen," at p. 79, or reproduced in the *British and Foreign Medico-Chirurgical Review* for January, 1862, p. 27.

In addition to the paralysis of the ciliary muscle, the sphincter pupillæ often loses its power of contractility, the pupil being then more or less dilated, either perfectly fixed (as in Cases XIII. and XIV.), or acting but sluggishly under the stimulus of light (Case XVI.). Cases XV. and XVII., in which the pupil contracted with the greatest activity, are, however, exceptions to this rule.

In judging of the action of the Calabar bean in these cases, two factors require distinctly separating,*—viz., 1, the improvement in vision resulting from a contraction of the pupil (which, by diminishing the size of the circles of dissipation, is in itself capable of accounting for a considerable share of the increase of visual power); and 2, that produced by the action of the Calabar bean on the ciliary muscle. In a case of hypermetropia, as may be inferred from what has preceded, this remark applies to distant as well as to near objects. Before, therefore, applying the Calabar bean, the effect of minute apertures in increasing the visual power, both for distant and near objects, should be carefully noted, so as to admit of comparison with the effects subsequently obtained by the Calabar bean. Without this precaution, it is impossible to separate the above-mentioned two factors in its action.

For the sake of clearness and facility of comparison, the annexed cases are arranged according to the following scheme, which, to some extent, may be of service as a guide to the order of investigating cases in practice :—

1. History.
2. Appearances of the eye (including the size of the pupil).
3. Visual power :—
    (A) For *distance*, before and after atropine,† with the effects of glasses in both cases.

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* In a series of cases reported in the *Ophthalmic Hospital Reports* for October, 1863, these are not separated, neither is the diagnosis of paralysis of accommodation rigidly established, or the state of refraction of the eye accurately given.

† In order to avoid errors in the examination of cases, it is better to defer the instillation of atropine until the previous results have been obtained with glasses and the Calabar bean.

(B) For *near objects*, before and after atropine, with the effects of glasses in both cases.

4. Effects of the Calabar bean:—
   (A) For distance.
   (B) For near objects.
   Giving the comparative experiments made with minute apertures previous to the application of the Calabar bean.

The report of Case XIII. is abridged from a detailed analysis which has already appeared in the *Ophthalmic Hospital Reports* for October, 1863, but is reproduced here for the sake of comparison with Case XIV., and on account of its details being brought down to a later date than in the previous report.

CASE XIII.—*Traumatic Paralysis of the Circular Fibres of the Ciliary Muscle (and Iris), occurring in a case of Hypermetropia* ($\frac{1}{16}$), *corrected (partially) by Convex Glasses, or by the Calabar bean.*

Fanny V., æt. 28, presented herself at the Ophthalmic Hospital, Southwark, on August 20th, 1863. Eight days previously, whilst opening a lemonade-bottle, the cork flew out, and struck her on the left eye, causing great pain and dimness of vision, which continued till she came to the hospital. When the patient was seen, the pupil was observed to be dilated and fixed; she could read no less type than No. 16,* and that but indistinctly. The fundus oculi was indistinct, as if from exudation.

℞ Potass. iodid., gr. ij, *ter die.*

August 24th.—The pain has left her; she now reads No. 14.

℞ Potass. iodid. *cum*
Quin. disulph., gr. i, *ter die.*

September 1st.—From the patient remarking to-day that her vision was greatly improved by looking through a pin-hole in a card, the optical condition of her eye was investigated more closely than had hitherto been done, the case having previously been taken rather for one of simple retinitis.

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* p. p. = nearest point of critically distinct vision (punctum proximum).
p. r. = furthest point „ „ (punctum remotum).
′ = feet; ″ = inches; ‴ = lines.
+ before the number of a glass = convex.
— „ „ „ = concave.

For the sake of conciseness, I shall omit the various steps in the examination, and group together the results of the observations made during the three following days.

The pupil of the left (injured) eye measured 3‴ in diameter, and was perfectly fixed, whilst that of the right measured but 2‴ in the same light, and contracted with the greatest activity. There was no evidence of any dislocation of the lens, either in a tremulous condition of the iris or in a direct objective examination. The ophthalmoscope disclosed a hypermetropic refraction of the eye. It seemed probable that some injury to the iris and ciliary muscle was the real nature of the case.

With the left eye at 20′ she read No. 22 imperfectly, but through an aperture of ½‴ diameter she could read No. 20, or with +16 alone No. 18 well. Finding that with +16 she could distinguish a much smaller type than with an aperture of ½‴ diameter, it was clear that the defect in vision was rather dependent on some deficiency in the refractive power of the eye than simply on the dilatation of the pupil.

At first, the right eye appeared to be emmetropic, as at 20′ she could read No. 18 with ease. But finding that low convex glasses did not deteriorate vision for distance, and that the near-point of this (right) eye was unusually distant, viz., 8½″,[*] we were induced to paralyse her power of accommodation in this eye; after which it was found that she could not read even No. 23, but with +16 she read No. 18 just as well as before any atropine had been applied, the direct image being also clearly seen in this, as it was in the left eye without an eye-piece.

With the injured eye she read No. 18 at about 13″, but with +16 she read No. 8 at the same distance. A square of the Calabar bean paper was now applied to this eye. In ten minutes the pupil was contracted to a diameter of about 1‴ (a little larger); she now read at 20′ No. 20 (which was a number lower than she could read through an aperture of 1‴ diameter previous to the application of the Calabar bean), and with +36 No. 19 well, her near-point for No. 10 being 18″. Although the pupil continued to contract till at last it was only ½‴ in diameter (where it remained fixed), no further improvement in vision ensued for distance, but she could now read No. 8 at 4″, and with +24 No. 2 at the same distance. This fact, combined with the previous observation made with the stenopæic hole, proved that the Calabar bean improved the patient's vision, not alone by its action on the pupil, but in a far greater degree by that on the ciliary muscle.[†]

The nature of the case was now clearly made out—viz., that it was one of a tolerably high degree of hypermetropia of both eyes, and that the defect of vision noticed in the left eye was due to a paralysis of the ciliary muscle, which prevented the patient correcting her hypermetropia by voluntary accommodation, but which was entirely supplemented by convex glasses, or restored to a great extent by the Calabar bean.

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[*] Erroneously printed as 3½″ in the *Ophthalmic Hospital Reports.*

[†] The necessity of employing a convex glass for attaining the maximum degree of acuteness of vision possible, depended probably on the ciliary muscle being too much injured to admit of perfect contraction even under a stimulus so powerful as that of the Calabar bean.

When last seen, on February 17th, 1864, her visual power was found to have become considerably improved. From September 5th, 1863, she had applied the solution of the Calabar bean regularly twice a day to the eye, but had discontinued its use for the last five days. Both pupils now acted readily in a full light; the right measuring 1‴, the left 1½‴ in diameter. The visual power of the right eye was as when she first came to the hospital.

February 17th, 1864.—*Left Eye:*—Pupil =1½‴ in diameter.

At 20′ reads No. 18, and somewhat more perfectly with +24
p.p. for No. 8=8½″.
„ No. 2 with +16=8½″.
„ No. 1 with +8=4″.
11.30 A.M. Calabar bean applied to left eye.
11.50 „ Pupil measures 1‴.
p.p. for No. 1=12″.
12. Pupil =1‴.
p.p. for No. 1=7½″.
12.20 P.M. Pupil =½‴.
p.p. for No. 1=8″.
At 20′ reads No. 18 perfectly.

From what precedes it is doubtful whether the Calabar bean improved the vision of the left eye by its action on the iris or that on the ciliary muscle. That part of her accommodation, however, which she, previous to the accident, used to correct her hypermetropia of this eye appeared to have become all but restored.

CASE XIV.—*Traumatic Paralysis of the Ciliary Muscle and Iris.*

UNDER THE CARE OF MR. LAURENCE.

Albert H., æt. 28, presented himself at the Ophthalmic Hospital, Southwark, on August 28th, with acute corneitis and hæmorrhage into the anterior chamber of the right eye, the results of a blow from a piece of putty. Under treatment, all the inflammatory symptoms subsided, the blood in the anterior chamber disappeared, and the cornea became quite transparent; but the pupil, on the 17th of September, was found to be widely dilated and fixed, measuring 3‴ in diameter, whilst that of the left (uninjured) eye measured but 1‴, and contracted briskly under the stimulus of light. There was no evidence of a dislocation of the lens discoverable, either from a tremulous iris, or from a direct objective examination. The patient stated that previous to the accident, he had never observed the slightest difference in the sight of the two eyes.

Visual Power :—

For distance :—

Right (injured) eye, at 20′ reads No. 23.
With +18, „ „ No. 18.
Left (sound) eye, „ „ No. 18.
+40 „ improves for No. 18.

For near objects :—

Right eye reads No. 10 at 8″.
With +4 reads with ease No. 1 at 4″.
„ +6 „ „ No. 1 at 6″.*
Left eye p.p. for No. 1 = 4″.

The ophthalmoscope disclosed a hypermetropic refraction of the right eye, and rather less so of the left; but there appeared to be nothing abnormal in either fundus.

On September 18th, a square of the Calabar bean paper was applied to the right eye, and a strong solution of atropine (grs. viii ad ℥j) to the left. In about an hour afterwards the right pupil had contracted to 2‴, and the left had dilated to 3‴ in diameter, when, with the right eye, he was able to read No. 21 at 20′ and No. 2 at 8″. With the left eye he could only read No. 20 at 20′ and required +40 to read No. 18 well. The first piece of Calabar bean paper was now removed from the right eye, and a second applied: but although the pupil of the right remained fixed at a diameter of 2‴ for about two hours, the vision continued to improve, till he was able to read No. 19 distinctly at 20′, and No. 1 at 4″, whereas, with an aperture of 2‴ diameter, previous to the application of the Calabar bean, he could read no lower a number than No. 22.

This case is very similar to the last, in being one of traumatic paralysis of accommodation, which could either be substituted by convex glasses, or, for the time, completely restored by the Calabar bean. The above results show that the contraction of the pupil after the application of the Calabar bean assisted considerably in improving vision; but from the fact that he continued to read smaller types, although the pupil remained stationary, it is evident that a still greater benefit was attributable to its action on the ciliary muscle, which continued to be acted on by the Calabar bean after this had ceased to affect the iris.

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* It might be objected that the convex glasses act simply by their magnifying power, but that this is not in any sense adequate to account for the improvement in vision will be seen from the following table :—

To an emmetropic eye—

+4 appears to magnify No. 1 only to about No. 5.
+6 „ „ „ No. 3.
+8 „ „ „ No. 2.

CASE XV.—*Paralysis of the Ciliary Muscle following suppressed Scarlatina.*

UNDER THE CARE OF MR. LAURENCE.

Amy M., æt. 7, a most intelligent child, was admitted on December 11th, 1863, as an out-patient at the Ophthalmic Hospital, Southwark, complaining of "dimness of sight." About six weeks previous to her admission she was suffering from suppressed scarlatina, and had lately experienced severe mental distress from the loss of a sister. On December 1st she complained of a "pricking" in the right eyelid, followed by impairment of vision for near objects, that for distance remaining unaffected. In about a week afterwards, the same defect occurred in the left eye, and subsequently she complained of double vision. Each pupil measured 1‴ in diameter, and contracted with the greatest activity in full daylight. There was a very slight insufficiency of the internal recti muscles, otherwise the single and combined movements of the eyeballs were perfect.

VISUAL POWER :—
For distance :—
Right eye at 17′ reads No. 20.
With +40 „ „ somewhat more clearly.
Left eye „ „ imperfectly.
With +40 „ „ perfectly.
For near objects :—
With either eye reads No. 14 at 8½″.[*]
(No. 14 is the smallest type she can decipher.)
With +4 reads No. 1 at 4″.
„ +6 „ „ 6″.
„ +8 „ „ 8″.

At 11.35 A.M., a square of Calabar bean paper was applied to the right eye, and atropine (grs. iv ad ℥j) to the left. At 12.5, the Calabar bean paper was removed, the right pupil having contracted to ½‴, and the left dilated to 2‴ in diameter.

VISUAL POWER :—
For distance :—
Right eye at 20′ reads No. 20. No glass appears to improve vision.
Left eye at 20′ reads No. 21. She now requires +24 to read No. 20.
For near objects :—
Right eye p.p. for No. 12=2¾″.
Left eye „ „ No. 16=6″.

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[*] According to Donders, the near-point in the emmetropic eye at 7 years is about 2½ inches (*op. supr. cit.*).

A stenopæic hole of a smaller diameter than her pupil, applied previous to the Calabar bean, did not in the least improve the vision of either eye.

From the above observations, coupled with the fact that the direct image could be fairly seen without an eye-piece, it was inferred that this patient had also been originally hypermetropic, and that she had partially lost the power of voluntarily accommodating the eye for distant as well as for near objects, which was, however, completely substituted by convex glasses, and to some extent temporarily restored by the Calabar bean. The mother was directed to apply the Calabar bean extract to the child's eyes every morning; but about five weeks elapsed before she again made her appearance at the hospital. It was then found that the power of accommodation had been spontaneously and completely restored, and that she could now (January 26th, 1864) read No. 19 at 20′, and No. 1 at 4″, with either eye. This case is instructive in showing how careful one should be in attributing effects to therapeutic agents, as upon inquiry it was found that the Calabar bean had not been applied at all to the patient's eyes since her last visit to the hospital, and she had merely been staying for a short time in the country, where her health and sight had gradually improved.

CASE XVI.—*Complete Paralysis of the Ciliary Muscle and partially of the Iris; from Debility.*

UNDER THE CARE OF MR. HOLTHOUSE.

Elizabeth R., a very intelligent child, æt. 11 years, came to the out-patients' room of the Ophthalmic Hospital, Southwark, on February 4th, 1864. For two or three weeks previously she had been suffering from dyspepsia and general debility, and during the last few days had complained of being unable to read small print, or to distinguish distant objects clearly. Both pupils measured 3‴ in diameter, and acted but sluggishly under the stimulus of light.

VISUAL POWER:—

For distance:—

With either eye at 20′ reads No. 22.
With +30 „ „ No. 19.

For near objects:—

With either eye, the nearest distance she reads No. 16=7″.
With +30 „ „ No. 12=9″.

In addition to +30 (the neutralizing glass for her hypermetropia) she requires

+4 to read No. 1 at about 4″.
+6 „ „ 6″.
+8 „ „ 8″.*

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* That these convex glasses did not improve simply by their magnifying power, *vide* note to Case XIV.

But with +30 alone, she reads No. 12 (the least type she can decipher) at 9″.[*]

After the instillation of a strong solution of atropine (grs. viij ad ℥j) on the following day, the visual power remained exactly the same as when she came to the hospital, showing that the paralysis of the ciliary muscle was as complete as it could possibly be. The refraction of the eye was hypermetropic: a narrow pigment line was present to the inner side of each optic nerve entrance.

At 4.7 P.M., the Calabar bean extract was applied to both eyes, which were in the same condition as above noted.

4.37. Both pupils measure 1‴ in diameter.

$$\left.\begin{array}{l}\text{At 20′ she reads No. 19}\\ \text{p.p. for No. 1=3″}\end{array}\right\}\text{ with either eye.}$$

With a stenopæic aperture of 1‴ diameter, previous to the application of the Calabar bean, she could read No. 20 at 20′, and No. 6 at 3″.

4.47. Both pupils contracted to ½‴ in diameter, but the visual power remains the same as at 4.37.

5.17. Both pupils measure ½‴ in diameter.

$$\left.\begin{array}{l}\text{At 20′ she reads No. 19}\\ \text{(No convex or concave glasses improve)}\\ \text{p.p. for No. 1=2″}\end{array}\right\}\text{ with either eye.}$$

With a stenopæic hole of ½‴ diameter, previous to the application of the Calabar bean, she read No. 20 at 20′ and No. 1 at 3″, which shows that, in this case, the contraction of the pupil was a very important element in the improvement of vision both for near and distant objects.

℞ Haust Quinæ cum Ferro, ℥j *ter die.*

When last seen, on February 15th, both pupils measured 3¼‴ in diameter. With either eye at 20′ she read No. 19, and No. 2 at 11″. With +30 she read No. 1 at 8″.

CASE XVII.—*Complete Paralysis of the Ciliary Muscle in a case of Hypermetropia* ($\frac{1}{40}$)*; probably from debility.*

UNDER THE CARE OF MR. HOLTHOUSE.

Eliza P., æt. 30, came to the Ophthalmic Hospital, Southwark, on February 1st, 1864, in a very feeble condition, and complaining that she was unable to see near objects distinctly. For the last two years, when reading a book, she had been compelled to hold it at a considerable distance off for distinct vision, especially at night, when she was in the habit of placing the candle between herself and the book. During the last eleven or twelve months these symptoms have become greatly aggravated, and of late, after reading or sewing for a short time, the eyes begin to "itch," and feel irritable. Both pupils measure 2¾‴ in diameter, and contract readily under the stimulus of light.

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[*] According to Donders, the near-point in the emmetropic eye at 11 years of age is about 2⅔ inches (*op. supr. cit.*); in our case, after correction of the hypermetropia, it is seen to be three times as distant.

VISUAL POWER :—

For distance :—

With either eye at 20′ she reads No. 19.

+40 enables her to see No. 19 a little more clearly.

For near objects :—

With either eye reads No. 2 from 12″ to 14″.

With +40 (the neutralizing glass for her hypermetropia) reads No. 1 at 10″.*

But with +40 alone she cannot read either No. 2, No. 4, or No. 6 at any distance less than 10″ from the eye.† With the ophthalmoscope nothing abnormal was discoverable in either fundus oculi.

At 4.20 P.M., the Calabar bean extract was applied to the eyes.

4.40. Both pupils have contracted to 1‴ diameter.

p.p. for No. 1 = 6″. Visual power for distance not tested.

With a stenopæic hole of 1‴ diameter, previous to the application of the Calabar bean, the nearest and only point of distinct vision for No. 1 was 10″, from which it is evident that the mere contraction of the pupil was not adequate to explain the great improvement in the visual power for near objects.

4.45. Both pupils are ½‴ diameter. At 20′ she is now unable with either eye to read any type less than No. 22, and requires 14-inch concave to read No. 20. All convex glasses deteriorate vision, and no concave glass enables her to read a less type than No. 20 ; p.p. for No. 1 = 5″.

With an aperture of ½‴, previous to the application of the Calabar bean, she read No. 19 at 20′ just as well as without it, and she read No. 1 in a range of 5½″ to 6½″.

The last observation made at 4.45, taken in conjunction with the previous comparative experiment of a stenopæic aperture, made it evident that the diminution in the power of vision could not be referred to the extremely contracted state of the pupil, but to the stimulating effect of the Calabar bean on the ciliary muscle, which was so great as to make the patient for the time, from having been previously hypermetropic, actually myopic, and that in a very marked degree.

I have lately noticed the same effect produced in another case of hypermetropia with paralysis of accommodation, in which the hypermetropia ($\frac{1}{18}$) became converted into a myopia of $\frac{1}{16}$ by the application of the ordeal bean.

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* The natural near-point for 30 years of age is about 5½″.

† After the full effect of instillating a strong solution of atropine had been obtained, the visual power was found to remain in precisely the same condition as previous to its application.

the two patients in themselves were anything but nervous or hysterical females.

The first of the above two cases is sufficiently remarkable to deserve a more extended notice here.

Case XVIII.

Marcella D. was 43 years old when she first consulted me. From childhood she had suffered from asthenopic symptoms; but for the last eight or nine years they had so increased in intensity as to utterly incapacitate her for all occupations that demanded close work of any description. Indeed, what was remarkable, she could not regard any object, whether close or distant, with any degree of attention without experiencing the most distressing sensations in the eyes. She had consulted, without avail, no less than sixteen or seventeen oculists. I found, on examination, that at fourteen feet she could not, with the naked eyes, read No. 22 with certainty; but with 14-inch convexes read No. 19 well. Repeated examinations yielded as their result that she was hypermetropic (manifestly) to a $\frac{1}{14}$, and also slightly presbyopic, so as to require 10-inch convexes for reading. With these glasses she was enabled to read from four to five hours at a stretch without experiencing any of her old asthenopic symptoms. Subsequently her manifest hypermetropia increased to a $\frac{1}{11}$, and she then required 7-inch convexes for reading. Latterly she became again slightly asthenopic, owing to insufficiency of the internal recti, for which I recommended division of the muscles, to which, however, I could not get her to consent, she being satisfied with the benefit she got from her convex glasses.

Stellwag v. Carion speaks of "cases of a high degree," .... in which "the hyperæsthesia of the retina and ciliary nerves renders even indefinite vision at distant objects with high illumination, contrasts of light, glaring colours, or strong reflexions, insupportable."

A little reflection will convince you how serious a disease we are considering, especially when you are dealing with poor patients, such as that humble section of the female community who gain their livelihood by the "needle,"—

> "With fingers weary and worn,
> With eyelids heavy and red."

Mackenzie very properly remarks: "It is an infirmity much more to be dreaded than the many disorders of the eye which superficial observation present a far more formidable appearance." And yet there is perhaps no one disease

CHAPTER IX.

ASTHENOPIA.

ASTHENOPIA, or weak sight, is succinctly defined by Mackenzie as "that state of vision in which the eyes are unable to sustain continued exercise upon near objects, although the patient, on first viewing such objects, generally sees them distinctly, can employ his sight for any length of time in viewing distant objects, and presents no external appearance of disease of the eyes." Travers described the symptoms of asthenopia as one of his varieties of "functional amaurosis," and considered loss of adjusting power as an "occasional symptom" ("Synopsis of the Diseases of the Eye," 2nd ed., 1821, p. 187). The above description is sufficiently accurate to give you a general idea of the disease we are considering; but it will be as well to follow out the symptoms into a little further detail. These are all the symptoms of muscular *fatigue* and nervous irritation. At first, as the word "fatigue" itself implies, they are not felt, but come on with a rapidity which may vary from a few seconds to an hour or more. Some patients cannot read two lines consecutively without an accession of asthenopic symptoms. They declare the letters "run into one another, and become misty and confused;" if they persist, the eyes ache and water till they are obliged to leave off from sheer pain and discomfort.* A little rest generally enables them to begin again, but I have met with a case in which the pain lasted for many hours after. In this same (and a second) case there existed an indescribable general feeling of nervousness and agitation, a sensation of nausea and vertigo, although the two patients in themselves were anything but nervous or hysterical females.

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* The mistiness of vision that ensues is probably partially a reflex phenomenon, as almost certainly the aching, injection (sometimes observed), and suffusion are evidences of reflex-irritation of the fifth and sympathetic nerves.

The first of the above two cases is sufficiently remarkable to deserve a more extended notice here.

Case XVIII.

Marcella D. was 43 years old when she first consulted me. From childhood she had suffered from asthenopic symptoms; but for the last eight or nine years they had so increased in intensity as to utterly incapacitate her for all occupations that demanded close work of any description. Indeed, what was remarkable, she could not regard any object, whether close or distant, with any degree of attention without experiencing the most distressing sensations in the eyes. She had consulted, without avail, no less than sixteen or seventeen oculists. I found, on examination, that at fourteen feet she could not, with the naked eyes, read No. 22 with certainty; but with 14-inch convexes read No. 19 well. Repeated examinations yielded as their result that she was hypermetropic (manifestly) to a $\frac{1}{14}$, and also slightly presbyopic, so as to require 10-inch convexes for reading. With these glasses she was enabled to read from four to five hours at a stretch without experiencing any of her old asthenopic symptoms. Subsequently her manifest hypermetropia increased to a $\frac{1}{11}$, and she then required 7-inch convexes for reading. Latterly she became again slightly asthenopic, owing to insufficiency of the internal recti, for which I recommended division of the muscles, to which, however, I could not get her to consent, she being satisfied with the benefit she got from her convex glasses.

Stellwag v. Carion speaks of "cases of a high degree," . . . . in which "the hyperæsthesia of the retina and ciliary nerves renders even indefinite vision at distant objects with high illumination, contrasts of light, glaring colours, or strong reflexions, insupportable."

A little reflection will convince you how serious a disease we are considering, especially when you are dealing with poor patients, such as that humble section of the female community who gain their livelihood by the "needle,"—

> "With fingers weary and worn,
> With eyelids heavy and red."

Mackenzie very properly remarks: "It is an infirmity much more to be dreaded than the many disorders of the eye which to superficial observation present a far more formidable appearance." And yet there is perhaps no one disease the true nature of which is more generally misunderstood. Mackenzie, after enumerating a great variety of causes, comes nearest to by far the most common one when he suggests that "the organs of adjustment ...... are probably the chief seat of the complaint." Donders, in calling attention to its very frequent dependence on a hypermetropic condition of the eye, has undoubtedly rendered a great service to practical ophthalmology; but at the same time my experience has taught me how greatly we should err, were we to exclusively assign it to this cause.

I believe the causes of asthenopia may, generally speaking, be grouped under the following three heads:—*

I. *Optical Defects of the Eye.*

II. *Deficient Power of the Internal Recti Muscles.*

III. *Hyperæsthesia of the Retina.*

I. *Optical Defects of the Eye.*

I must, *in limine*, remark that most persons we are now speaking of apply to the surgeons solely for their asthenopia; they never suspect the least wrong with their sight; on the contrary, they declare they see remarkably well generally, and that it is only when they try to read or work any length of time they feel their eyes "weak."

The most frequent optical defect is a hypermetropic condition of the eye. Part of the accommodation of such an eye is expended in neutralizing its defective refraction, and, as a consequence, when the patient employs his eyes on near objects, he unnaturally "forces" his accommodation, so that the ciliary muscle is wrought up to a degree of tension that soon obliges it to give in, and thus are caused all those symptoms of muscular and nervous irritation and fatigue, and consequent indistinctness of vision, which we have already described. You may for a few minutes sustain a heavier weight than your muscles will naturally support; but try to prolong the effort, and you will soon experience that sense of inability and fatigue which the ciliary muscle feels in another way.

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* I find that the same classification has been independently adopted by Stellwag von Carion ("Lehrbuch der Augenheilkunde." Vienna, 1861, p. 658). He recognises two species of asthenopia:—1, an accommodative; 2, a muscular; and with both "a hyperæsthesia of the retina and ciliary nerves in close pathogenetic relation therewith."

Case XIX.

Robert W. W., æt. 15, consulted me, on November 15th, 1862, on account of asthenopic symptoms. He had been using 12-inch convex glasses for about three years and a half; but they no longer helped him. I found that at 20 feet he read with the right eye No. 21, and with +9 No. 20, to read which, after instillation of atropine, he required +7; with the left eye he read at 20 feet No. 23, with +6 No. 22, to read which, after atropine, he required +5. I prescribed a 9-inch convex glass for his right eye and a 6-inch one for his left eye. I saw him about a year afterwards, when he informed me the glasses had completely cured his asthenopia.

But I have also met several cases of asthenopia which were due to myopia. This may exist in a very slight degree. A woman, aged 33, applied to me for intense asthenopia. She was cured, and that there and then, by the use of a pair of 40-inch concave glasses. Within a very brief period two ladies consulted me for asthenopic symptoms, which I found depended on presbyopia, and were remedied by suitable convex glasses. Mr. White Cooper has (*op. cit.*, p. 123) remarked the same thing, and at p. 92 quotes a peculiarly acute case that occurred in his own practice. In short, any optical defect of the eye attended with limited power of accommodation may be the cause of asthenopia, and therefore it is always absolutely necessary in these cases to subject the eyes to a rigid optical examination.

I may here attract attention to a very important class of cases which I believe have hitherto escaped attention. I have met with asthenopia between the ages of about 20 and 35 where no defect of refraction was by the most delicate tests detectable, nor did the accommodation at first seem hardly impaired. Yet in these cases the patient was at once relieved of all asthenopic symptoms by very low-powered convex glasses ($\frac{1}{40}$ to $\frac{1}{60}$). Such cases are, I believe, true instances of "premature presbyopia." With these same glasses distant objects were misty and confused.

II. *Deficient Power of the Internal Recti Muscles.*

This is the disease which the German authors characterize as "insufficiency" of the internal recti. You will find an elaborate description of it at p. 242 of Alfred Gräfe's "Motilitäts-Störungen des Auges," a work which, embodying all the profound researches of his illustrious teacher, Professor v. Gräfe, will amply repay the serious study of those who wish to have any clear idea of the action and derangements of the muscles of the human eye.

Weakness of the internal recti may effect one or both muscles—most commonly both. Such a case is detected by observing that when we, covering one eye with the hand, direct the patient to regard a near object with the other, the covered eye deviates outwards—in a word, the patient has, under these circumstances, a divergent squint of that eye. As soon as we remove our hand, the divergent eye at once turns inwards, and resumes its symmetrical position to the other eye.* There are many cases of this infirmity, which would be, and constantly are, overlooked, from neglecting this simple method of examination. Again, if we before a healthy eye place a prism with the base outwards or inwards, the person at first sees double; but, if the angle of the prism is not too great, he soon, in order to overcome the consequent double vision, respectively squints inwards or outwards with the eye before which the prism is held. In cases of weakness of the internal recti, you will find that this muscular power of neutralizing diplopia by convergence of the eye is diminished, that by divergence increased; so that, *e.g.*, in a case mentioned by Alfred Gräfe, "the patient possessed the power of overcoming prisms up to 18°, with the base turned inward before the left eye by a corresponding degree of strabismus divergens. Prisms of 2° and 4°, with the base placed outwards, he only momentarily overcame by an opposite (convergent) squint." If a prism with its refracting angle upwards be held before one eye, any object (such as a dot of ink on a piece of paper) seen with both eyes together appears double, the image through the prism being directly above that seen with the other (naked) eye, thus:

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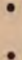
* In the first case the eye, excluded from common vision with its fellow-eye, is at liberty to assume that position indicated by the relative strengths of the two antagonist muscles, the internal and external recti. In the second case the participation in the act of vision forces the weak internal rectus to prematurely exert itself, to avoid the crossed double images that would necessarily result from any divergence of its eye. In this way an eye affected with weakness of the internal rectus assumes a divergence, if the patient is in reverie, if the affected eye becomes the subject of cataract, &c. In this latter case a successful operation for cataract may at the same time restore the symmetry of the eyeball. The test we have just been discussing becomes still more evident if the object be held, not directly on a level with, but above that of the eyeballs. We may further add, in reference to this test, that the fusion of the double images produced by holding a prism with its base inwards before one eye, by the compensating action of the external rectus, becomes easier the nearer the object, and *vice versâ*; so that we can overcome the "doubling" action of stronger prisms for near objects than for distant ones. If the prism is held with its base outwards, the very reverse of the above holds good, till the object is placed at, or within, the near-point, when the internal recti appear to be the stronger. In weakness of these muscles the preponderance of abduction for the usual distance of reading, writing, &c., is, as we have seen, well marked, and, if the weakness be at all excessive, even for greater distances.



The faculty of single vision with two eyes is thus almost insuperably annihilated, on account of the very slight power we possess of isolating the action of either the superior or inferior recti muscles, so as to fuse the double images (as is readily done, as we have mentioned above, by the lateral ocular muscles). Under these circumstances, the accommodative action of the internal recti being no longer called into play, each eyeball assumes that position indicated simply by the relative strength of the internal recti. Should this be normal, the dots will assume the position delineated above; but should either, or both, internal recti be preternaturally weak, the eyeball, or balls, will, from the preponderating strength of the external rectus, pass into a state of divergent squint, and thus crossed double images arise. The final result is that the two dots exhibit in such a case not only a difference of height, but, in addition, a lateral crossed separation. The images then appear thus:

A second prism held with its angle outwards before the second eye destroys this lateral separation, leaving the difference of height unchanged. *The strength* (= *number* *of degrees) of the prism necessary for this purpose affords a direct measure of the degree of weakness of the internal rectus.*

It has been thought weakness if the recti interni is confined to myopic patients. I believe it is by far most frequently met with in such cases, especially if the myopia is high, in which, ultimately, you will very commonly find a confirmed divergent squint and consequent amblyopia.

But I have met with a case of hypermetropia of $\frac{1}{14}$, in which the most intense asthenopia was caused by weakness of the internal recti, with a second of almost equal intensity in a hypermetropia of $\frac{1}{30}$, and several other less severe cases. I may here remark that, owing to the connexion between accommodation and convergence of the optic axes, two causes, acting and reacting upon each other, are at play in producing the asthenopic symptoms that attend weakness of the internal recti.

Asthenopia from this cause, occurring in a myopic patient, may be sometimes relieved by the use of glasses, which enable him to read at a sufficient distance from the eyes to moderate their convergence to a degree that entails but a very slight action of the affected muscles; or by the systematic application of prismatic glasses with the bases turned outwards, the internal recti may be gradually strengthened in the effort they will instinctively make by converging the optic axes to overcome the crossed double vision the prisms would otherwise cause. Prismatic glasses with the bases turned inwards have no effect in radically curing the disease—on the contrary, rather encourage it, but render vision more distinct for the time and relieve the asthenopia by supplementing the action of the internal recti. Thus, in a case of this kind I found the patient, who had a myopia of $\frac{1}{3}$, read a type of about No. 6 easily with a prism of 11°, the base inwards applied to the right eye, although she could hardly read the type at all with the unaided eyes. The last resource is total or partial division of the external rectus muscle.

III. *Hyperæsthesia of the Retina.*

Besides the above cases of asthenopia, we every now and then meet with ones which are attended by a general low state of the system, often associated with photophobia. These generally get well under the use of tonic medicines and regimen, and therefore may not unreasonably be ascribed to hyperæsthesia of the retina, or perhaps even they may depend upon some temporary asthenic state of the organs of adjustment. The asthenopia often met with after exhaustive fevers, diphtheria, &c., probably belongs to this category.

CHAPTER X.

THE CONNEXION BETWEEN CONVERGENT STRABISMUS AND HYPERMETROPIA.

THE terms "total," "manifest," and "latent" hypermetropia have already been explained (p. 57). Donders recognizes three forms of manifest hypermetropia dependent on the amount of accommodation the eye possesses.

(*a*) *Absolute* manifest hypermetropia: Let the patient accommodate as much as ever he can with a maximum convergence of the optic axes, he still fails to neutralize all his hypermetropia; a portion of it still remains uncorrected by any natural effort at his command. Distinct vision is impossible under any circumstances without the aid of convex glasses.

(*b*) *Relative* manifest hypermetropia: The patient possesses sufficient accommodating power to neutralize his manifest hypermetropia, but can only avail himself of it on one condition, viz., that he converges the eyes to a nearer point than that for which he accommodates them. He is only able to elicit sufficient accommodation to neutralize his hypermetropia for any point by converging his eyes to a nearer one than that at which the point in question is really situated. And this is what such a patient may actually do—an additional proof that accommodation and convergence are not indissolubly connected acts. The patient, unaided by glasses, would be thus theoretically placed in this unfortunate position: if he sees an object single, he does not see it accurately: if he sees it tolerably accurately, he sees it double. How the patient may obviate the double vision in the latter case we shall see presently. Relatively to any point of convergence, with single vision, then, the hypermetropia is, in truth, absolute.

(*c*) *Facultative* manifest hypermetropia: The patient possesses sufficient accommodation to neutralize his hypermetropia without the necessity of any undue convergence of the eyes, as was the case in relative hypermetropia.

A little consideration will show that two factors determine the kind of hypermetropia a patient experiences: firstly, the total amount of hypermetropia; and, secondly, the total amount of accommodation he possesses. If the patient's total hypermetropia exceeds his total accommodation, absolute hypermetropia must necessarily result; if it does not exceed it, but is still considerable in proportion to it, relative hypermetropia will probably ensue; while, if it is inconsiderable in proportion to the accommodation, facultative hypermetropia arises. As the amount of accommodation diminishes (vide p. 74) as age advances, facultative hypermetropia will give way to relative, and relative to absolute.

It had been long known that persons who squinted inwards suffered also from defective vision; but this knowledge was, and even now is, not so widely diffused as, in the interests of humanity, it should be. A squint is, even in these days, unfortunately but too often regarded as a mere personal deformity, which may, or may not, according to the patient's position in life, be well left to his own taste and discretion to be cured of, or not.

It had been observed by various authors that persons who squinted inwards presented a peculiar form of "short sight," which was remedied, not by concave, but by convex glasses. I myself, some years ago, published a paper on this subject in the *Glasgow Medical Journal*, entitled "On the Short Sight of Squinters," in which I adduced several cases of this to me, at that time, inexplicable contradiction of facts. After Donders had recognised the widely spread diffusion of hypermetropia, he further remarked that most all cases of ordinary convergent squint were accompanied by this optical defect. Subsequent researches have fully proved the important fact that hypermetropia is in these cases the *cause* of the squint, and that this latter is a mere symptom and nothing more.

Convergent squint is, in most cases, caused by relative* hypermetropia. In this case the patient, if unaided by art, has, as follows from what I have above said, three alternatives: 1°, imperfect, single, binocular vision; 2°, more perfect, double, binocular vision; 3°, perfect, single, monocular vision. The second alternative would be more confusing to the patient than the first. As a rule, he prefers the first.

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* As will be seen from what follows, a person with absolute hypermetropia would gain little or nothing by squinting; whilst a person with facultative hypermetropia sees accurately without it.

The third alternative ensues in the act of squinting. The object of the squinter is to obtain perfect, single, monocular vision. In order to attain *perfect* vision there must be—

(*a*) A perfectly accurate image of the object projected on the retina of at least one of the eyes. In relative hypermetropia this is only possible when the lines of vision of the two eyes intersect each other in a point nearer than the object.

(*b*) The image must fall on the macula lutea of that eye, because this portion of the retina is endowed with the greatest functional perfection.

When conditions (*a*) and (*b*) are both fulfilled, the line of the vision of the other eye, as it intersects that of the former eye at a point nearer than the object, must of necessity be directed inwards past the side of the object; and this deviation amounts to a squint. I conceive that the squint serves a second [perhaps more important] purpose—namely, to throw the image on an eccentric, less sensitive, part of the retina.* This image the patient ignores by a process of mental abstraction, in which he is further aided by the circumstances under which the squint usually arises: "those which diminish the value of binocular vision"—*e. g.*, a natural difference of refraction in the two eyes, an amblyopic state of one eye, spots on the cornea, &c. To these I would add the general inertia of the retina, which, as will be shown further on, exists more or less in all hypermetropic eyes. I think myself that habit has a great deal to do with squinting in these cases. Myopic persons, after they have found out that they see more distinctly with one than with two eyes, often get into the way of habitually reading with one eye. I have done so myself. Similarly, I conceive, after a hypermetropic person has once, perhaps in the first instance by mere chance, discovered how much better he sees with one eye alone than with the two together, he tries it again and again, till it becomes a confirmed habit. I have met with several hypermetropic persons who were perfectly conscious that whenever they wished to see an object distinctly with one eye, they instinctively turned the other in. Many hypermetropics, who are not aware of ever having squinted in their lives, may be made to do so by shading one eye; they may then be often observed to squint with the shaded eye, as soon as the patient regards attentively any near object with the other eye. Again, if a person with normal vision be rendered artificially hypermetropic by concave glasses, he may often be seen to squint with one eye as soon as he endeavours to see any object distinctly.

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* Dr. Rainy has, in a letter, mentioned to me a remarkable case of paresis of the ocular muscles, in which, "on moving an object in a certain direction, the images seen by the two eyes appeared wider and wider apart, until *suddenly* one of them disappeared. The object had not gone out of the field of vision of the deviated eye, but I believe that its image came to fall on a part of the retina sufficiently eccentric to admit of its suppression."

The squint is at first occasional, periodic, only, and may in this stage be generally cured without an operation by convex glasses, prisms, or Javal's stereoscopic method of ocular gymnastics. Indeed, after the operation for convergent strabismus, the tendency to squint still exists—for the operation is powerless in removing the fundamental origin of the squint, the hypermetropia—and may reassert itself in all its former intensity, if the patient does not, at any rate for all close work, use proper convex glasses.

CASE XX.

I operated by double tenotomy on a boy, æt. 11, for a concomitant convergent squint of the right eye, both eyes being hypermetropic to a $\frac{1}{18}$, and having an acuteness of vision (*S*) of about $\frac{1}{2}$. When I saw him about three weeks after the operation, I found the squint had recurred to a degree of $2'''$ in the right eye, although I was convinced I had performed the tenotomy very completely. I then ordered him to wear 16-inch convex glasses. When I again saw him, three weeks later, the squint had disappeared, and had not returned on a subsequent visit from him three months afterwards.

In how many such cases a second operation has been unnecessarily performed, from the operator's impression that the muscle had not been "completely" divided in the first operation, I am not in a position to say.

After a squint has existed any considerable length of time it becomes confirmed. The eye turns in, more or less, always, and from this time forwards *its vision gradually diminishes.* This arises, I believe, from a secondary change occurring in the retina. Hypermetropia mostly depends upon a congenital smallness of the eye, and, in a restricted sense, may thus be regarded as an instance of arrest of development. It is not unnatural, under such circumstances, to suppose that the retina participates in the general want of formation, and this view is borne out by facts. The acuity of vision is generally somewhat less than normal in all hypermetropic eyes (altogether apart from any exceptional astigmatism), and is markedly so in all the higher degrees. The following table contains an analysis of the acuteness of vision in 112 hypermetropic eyes which I have carefully examined during the last five years :—

Summary of the Acuity of Vision (S) *in* 112 *Hypermetropic Eyes.*

Degree of Hypermetropia.	Average *S.*	Degree of Hypermetropia.	Average *S.*
$\frac{1}{3\frac{1}{2}}$ to $\frac{1}{4\frac{1}{2}}$	$\frac{1}{4}$	$\frac{1}{18}$ to $\frac{1}{20}$	$\frac{3}{5}$
$\frac{1}{5}$ „ $\frac{1}{10}$	$\frac{1}{3}$	$\frac{1}{20}$ „ $\frac{1}{36}$	$\frac{9}{13}$
$\frac{1}{10}$ „ $\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{40}$ „ $\frac{1}{50}$	$\frac{2}{3}$

A glance at the table proves the important fact that the acuity of vision (*S*) exhibits a progressive diminution as the degree of hypermetropia rises. Donders remarks the same thing, "that even after the correction of the astigmatism of the hypermetropic, the acuteness of vision usually remains rather considerably below the normal." Yet when we come to inspect such eyes with the ophthalmoscope, we can detect nothing morbid beyond the low refractive state of the eye. The only explanation that I can give of the amblyopia in hypermetropia is, as I have before said, that the retina itself is imperfectly developed. Admitting such a predisposition to imperfect visual perception, we might, *à priori,* have assumed, what is found by experience, that an eye which has not participated in vision for perhaps many years, at last practically loses its sight.

This assumption is fully borne out by facts. The table on the next page exhibits the acuity of vision (S) in 33 cases of convergent squint. H_1 is the hypermetropia of the primarily squinting eye, H_2 that of the secondarily; S_1 the acuity of vision of the former, S_2 that of the latter.*

In no less than 26 of the 33 cases is the acuity of vision of the squinting eye less than that of the straight eye; the average ratio of the one to the other being, indeed, so low as 1 to 6. A comparative reference to the column "Age," and to the table given at p. 37 of the influence of age in diminishing the acuity of vision, proves that this factor may be practically left out of consideration in the preceding deduction. One very important fact is rendered probable by this table: that the duration of the squint has a powerful influence in diminishing the patient's vision. The necessary practical corollary to this is, that a squint is not an affection to be temporized with; it must be cured as early as possible, whether by operation or otherwise. If it is not cured, the patient gradually, but surely, loses all useful vision with the squinting eye. A loss of binocular vision is not so small a loss as may be imagined. The power of judging of distance is deteriorated, and thus the patient is exposed to a variety of accidents. Should he meet with one to the straight eye, he runs the risk of becoming blind altogether.

It would be foreign to the scope of this work to describe the several methods of ocular tenotomy; all I would here remark is, that for the cure of squint I have practised both the subconjunctival section of the ocular muscles and the old operation of Dieffenbach; and I must confess that, prepossessed as I was at first with the former operation, I have again reverted to the older one, which I believe, performed cautiously, with the addition of an *ad libitum* limiting suture, surpasses the subconjunctival one—not in certainty, but in the power it affords us of very nearly regulating our operation in

---

* In the table an Acuity of Vision under $\frac{1}{10}$ I have arbitrarily designated by 0.

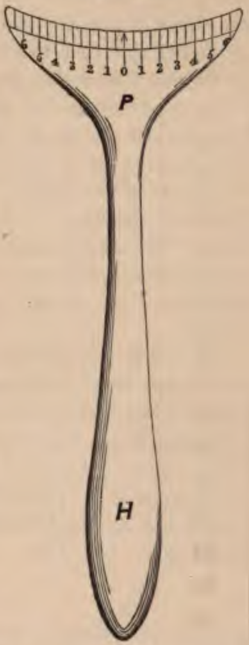
ACUITY OF VISION (*S*) IN THIRTY-THREE CASES OF MONOLATERAL CONVERGENT STRABISMUS.

No.	Age.	Duration.	Degree of Inversion.	H_1	H_2	S_1	S_2
1	16	Congenital	2‴	$\frac{1}{24}$	$\frac{1}{24}$	1	1
2	12	Congenital	?	$\frac{1}{20}$	$\frac{1}{20}$	0	$\frac{1}{2}$
3	13	9 years	2‴	$\frac{1}{10}$	$\frac{1}{16}$	$\frac{2}{3}$	$\frac{2}{7}$
4	20	Congenital	2½‴	?	$\frac{1}{40}$	0	$\frac{2}{3}$
5	19	?	?	?	?	$\frac{1}{10}$	1
6	15	?	3‴	$\frac{1}{16}$	$\frac{1}{30}$	$\frac{2}{7}$	1
7	9	6 years	3‴	$\frac{1}{20}$	$\frac{1}{60}$	$\frac{1}{2}$	$\frac{1}{2}$
8	12	8 years	2½	$\frac{1}{11}$	$\frac{1}{11}$	$\frac{1}{2}$	$\frac{1}{2}$
9	20	18 years	2‴	$\frac{1}{10}$	$\frac{1}{36}$	0	$\frac{1}{2}$
10	22	15 years	2‴	?	$\frac{1}{20}$	0	$\frac{2}{3}$
11	10	?	5‴	?	?	0	$\frac{2}{3}$
12	40	14 years	1½‴	$\frac{1}{10}$	$\frac{1}{12}$	$\frac{1}{5}$	$\frac{1}{5}$
13	boy	11 years	2‴	$\frac{1}{10}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{2}$
14	19	?	1½‴	?	$\frac{1}{10}$	0	$\frac{1}{2}$
15	20	Congenital	5‴	$\frac{1}{20}$	$\frac{1}{30}$	$\frac{2}{7}$	$\frac{2}{3}$
16	14	9 years	2‴	?	?	0	$\frac{2}{3}$
17	21	13 years	2‴	$\frac{1}{14}$	$\frac{1}{14}$	$\frac{1}{10}$	1
18	20 (?)	Congenital	4‴	$\frac{1}{30}$	$\frac{1}{30}$	$\frac{1}{10}$	$\frac{2}{3}$
19	22	14 years	3‴	?	?	$\frac{1}{10}$	$\frac{2}{7}$
20	11 (?)	?	3‴	$\frac{1}{7}$	$\frac{1}{10}$	$\frac{2}{7}$	1
21	27	?	1½‴	?	?	0	1
22	15	12 years	?	?	?	0	1
23	10	Congenital	2‴	$\frac{1}{20}$	$\frac{1}{20}$	$\frac{1}{10}$	$\frac{2}{7}$
24	17	12 years	2‴	?	?	0	?
25	42	Many years	Very slight	$\frac{1}{36}$	$\frac{1}{36}$	$\frac{1}{2}$	$\frac{2}{3}$
26	32	?	1‴	$\frac{1}{18}$	$\frac{1}{40}$	$\frac{2}{7}$	$\frac{1}{2}$
27	14	Congenital	1¾‴	$\frac{1}{18}$	?	$\frac{1}{40}$	$\frac{2}{7}$
28	17	?	1½‴	$\frac{1}{11}$	$\frac{7}{20}$	$\frac{2}{7}$	$\frac{2}{3}$
29	38	30 years	2‴	0	$\frac{1}{20}$	0	$\frac{1}{2}$
30	15	11 years	2‴	0	0	0	$\frac{1}{2}$
31	17	3 years	3‴	$\frac{1}{9}$	$\frac{1}{24}$	$\frac{1}{2}$	$\frac{1}{2}$
32	15	13½ years	5‴	$\frac{1}{18}$	$\frac{1}{18}$	$\frac{1}{10}$	$\frac{1}{2}$
33	15	2 years	3‴	$\frac{1}{10}$	$\frac{1}{16}$	$\frac{1}{10}$	$\frac{1}{2}$

proportion to the amount of effect we wish to produce. This may be estimated by means of an instrument, of which the annexed description is from the second number of the *Ophthalmic Review* :—

“A STRABISMOMETER.

FIG. 30.



“The object of this instrument is to measure precisely and readily the linear amount of deviation of a squinting eye. The method that has hitherto been adopted for this purpose is described by Dr. Alfred Gräfe in the following words :—‘To express the amount of displacement of a deviated eye, it is better in practice to make such determinations, as von Gräfe does, by linear than by angular measurements, the estimation of the former being much more certain than that of the latter. Mark on the lower eyelid the point which corresponds to the [vertical] diameter of the pupil of the deviating eye ; then [by excluding the other eye from vision] cause the patient to fix an object with this same eye, and again mark the point corresponding to the [vertical] diameter of the pupil : the distance of these two points from one another is the linear expression of the deviation in question.’* There are several objections to this method. It is tedious : it involves four distinct acts—two on the part of the patient and two on that of the surgeon—both inaccurate in their character. The deviated (squinting eye) is not at all uncommonly amblyopic ; and hence its power of fixation uncertain. The ‘marking’ of the lower eyelid involves several inaccuracies. The marking often irritates the eyelid sufficiently to prevent the patient keeping it perfectly fixed in one position. The mark itself, made by pen and ink, embraces three sources of error : its difficulty of execution, its necessary irregularity and thickness, and an inconvenient method of sighting the diameter of the pupil. This method of von Gräfe's contains, I think, so many elements of error as to cast serious doubts on the numerical precision of the data it affords. I, therefore, some years ago had an instrument (Fig. 30) constructed, which I conceived might obviate these various objections. It consists of an ivory plate (*P*), moulded (from actual experiments on the living subject) to the conformation of the lower eyelid, the free border corresponding to that of the lid. This border is graduated in such a manner, that, while its centre is designated by 0, Paris lines and half-lines are marked off on each side of 0, in the manner indicated in the annexed diagram. Attached to the plate is a handle (*H*). The application of this strabismometer is obvious. The ivory plate is applied to the lower eyelid, the borders of the two corresponding. If the cornea is central, the vertical diameter of the pupil corresponds to 0; if inverted, to a graduation on the inner side of 0; if everted, to one on the outer side of 0. These remarks hold good when the patient is regarding a distant object. It may be objected to this method, that as the plate of the instrument necessarily cannot exactly correspond in size and conformation to every eyelid to which it is applied, and secondly, as the non-deviated eye itself may not be exactly central, the resulting determinations must be inexact. After some years' experience of its use, I (and others who have employed the instrument) find these objections are practically of no moment. Moreover, our object in practice is to estimate rather the relative *differences* of position of the two eyes than their individual absolute positions, and the data afforded by the strabismometer are always exact in this point of view. At the time of my constructing this instrument, I sent one to my friend Dr. Snellen, of Utrecht, and one to Dr. Liebreich, then of Berlin, now of Paris. The only literary notice of the strabismometer I published is contained in a foot-note to page 8 of my address on 'The Progress of Ophthalmic Surgery' (read before the North London Medical Society on February 11, 1863), where I say, 'The author may here perhaps allude to a very simple little instrument he has constructed for the linear measurement of the exact amounts of deviation of the eyeballs in cases of strabismus. It may be had of Messrs. Weiss.'

---

* “Klinische Analyse der Motilitätsstörungen des Auges,” von Dr. Alfred Gräfe, Berlin, 1858, p. 27.

"It will be readily seen that by the strabismometer the relative positions of the corneæ may be ascertained for *all* positions of the eyes; and, further, that it is equally applicable to cases of divergent strabismus.

"I have found it a convenient notation to designate by *plus* (+) all positions of the centre of the cornea to the inner (nasal) side of 0; by *minus* (–) those to the outer side. Thus, if the patient regards a distant object in the middle line, a convergent squint of the right eye of 2 lines would be briefly designated as :—

l. e. : o
r. e. : +2;

a divergent squint of 3 lines of the left eye as :

r. e. : o
l. e. : –3;

a convergent squint of both eyes, in the right of 2½ lines, in the left of 1 line as :

r. e. : +2½
l. e. : +1, &c. &c.;

and the same method is applicable to all lateral positions of the eye, whether squint exists or not."

I would finally remark, that of all cases of strabismic amblyopia which I have examined with the ophthalmoscope, I cannot find a single one in my notes in which anything morbid was observed in the eye beyond a hypermetropic refraction. The amblyopia is, then, probably the result of a species of chronic paralysis, or inertia of sensibility of the retina, predisposed to in the first instance by imperfection of development, directly caused by the practical exclusion of the squinting eye from the act of vision.

THE END.

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